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LOCALIZER RANGE RATE MEASUREMENT SYSTEM,(U)
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Report No. FAA-RD-80-92

LOCALIZER RANGE RATE MEASUREMENT SYSTEM

Forrest Yetter

MARCH 1981

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16. Abstract

The FAA Wind Shear Project Office has determined that groundspeed is a desirable parameter for a wind shear detection system. This report describes range rate measurement equipment that meets both the accuracy and response time requirements for groundspeed on final approach. The cost of the described equipment is considerably less than current shelf hardware, e.g., INS and Doppler navigators, that also meet these measurement requirements.

The described system provides one-way differential ranging, operating on the Doppler principal. The localizer carrier antenna pattern is modulated by a 5 KHz precision frequency controlled tone. This signal is received by the aircraft's ILS localizer receiver, and its demodulated tone is processed to measure the Doppler shift of the tone. The unique differential ranging processing method used in this equipment, which accurately measures frequency differences of less than one thousandth of a Hertz, is described in more detail, the Forrest Yetter U.S. Patent Application Serial No. 06/085,66A. The issued patent will be assigned to the U.S. Government.

This system has been successfully flight tested several times, and copies of flight check recordings are shown in this report.

17. Key Words
Differential Ranging
Doppler
Groundspeed
Range Rate
Wind Shear

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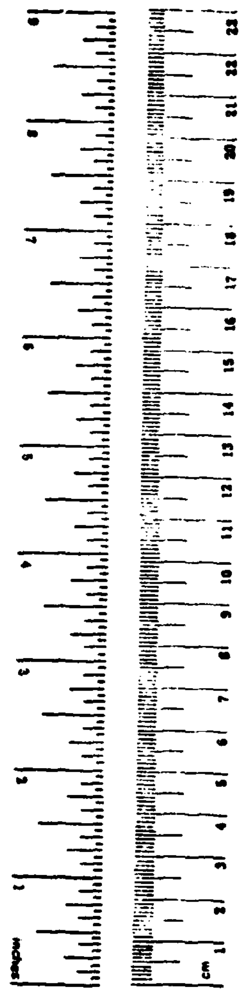
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

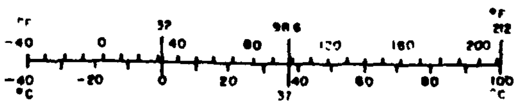
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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FOREWORD

The Localizer Range Rate System described in this report was designed, fabricated and tested by personnel of the FAA Navigation and Landing Division, Systems Research and Development Service, Washington, D.C.

Flight testing of this system was performed by the U.S. Air Force 4950th Test Wing Det. 1, Andrews Air Force Base, Maryland under the direction of the Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio.

1. INTRODUCTION

Wind shear related aircraft accidents and incidents motivated formation of the FAA Wind Shear Project Office for related research and development activity. This effort emcompassed several different areas ranging from improved wind shear forecasting techniques to airborne wind shear devices, one being to provide accurate ground speed information to aircraft while on final approach.

The use of ground speed information by the flight crew has been demonstrated as an ingredient of a reliable wind shear information system. The accuracy and timeliness of the ground speed information is of the utmost importance. Current systems that meet these requirements are relatively expensive, therefore effort was directed toward development of a low-cost ground speed system. This report describes such a system which has been fabricated as a flyable brass board and successfully flight tested during this program.

2. DESIGN GOALS

The design goals for the equipment described by this report, for ground speed measurement in a wind shear environment during final approach are as follows:

Coverage	Same as localizer
Accuracy	± 5 knots (2σ)
Velocity	80-250 knots
Velocity Response	3 knots/sec
Update rate	0.3 Hz

3. OPERATING PRINCIPLE

The operating principle of this range rate measurement system is illustrated by Figures 3-1 and 3-2. A conventional one-way Doppler, using the

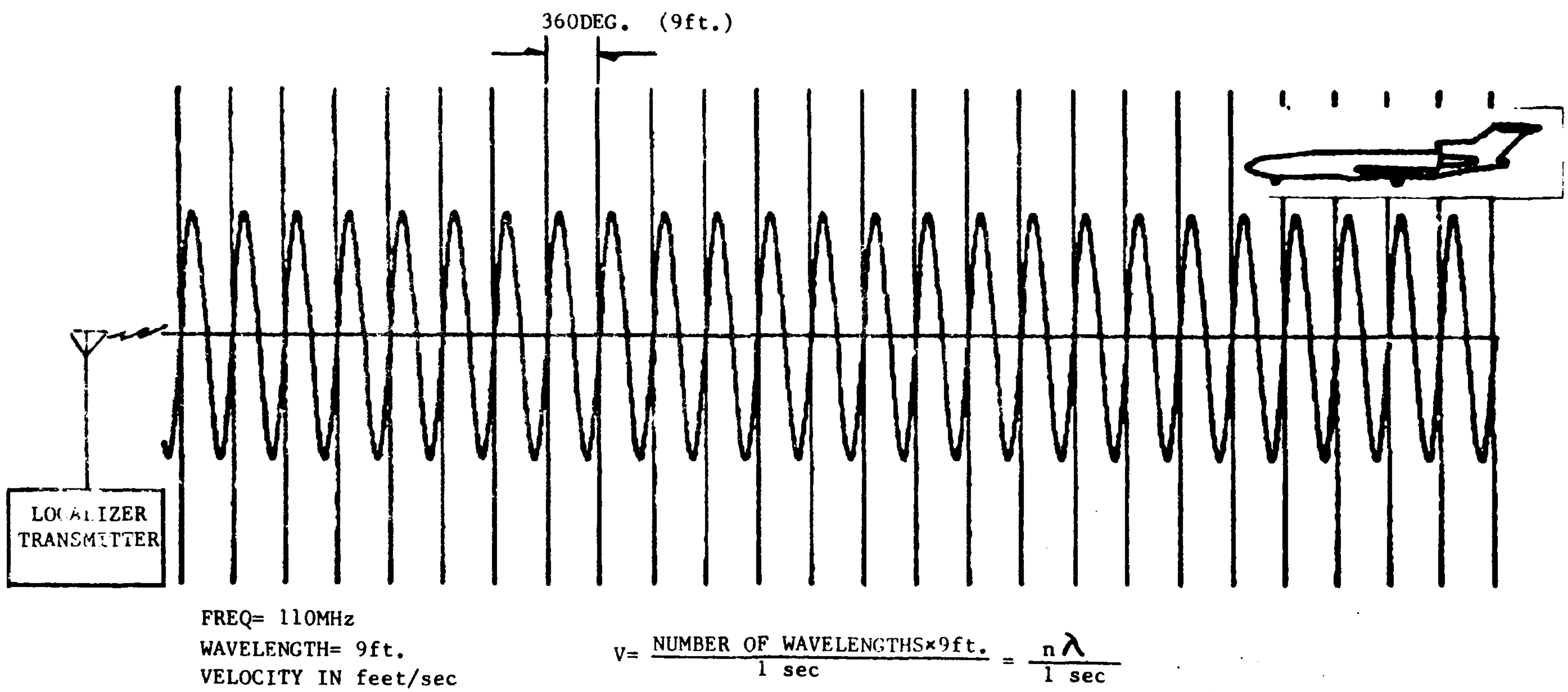


Figure 3-1. Approach and Landing Doppler Range Rate System (Frequency Domain)

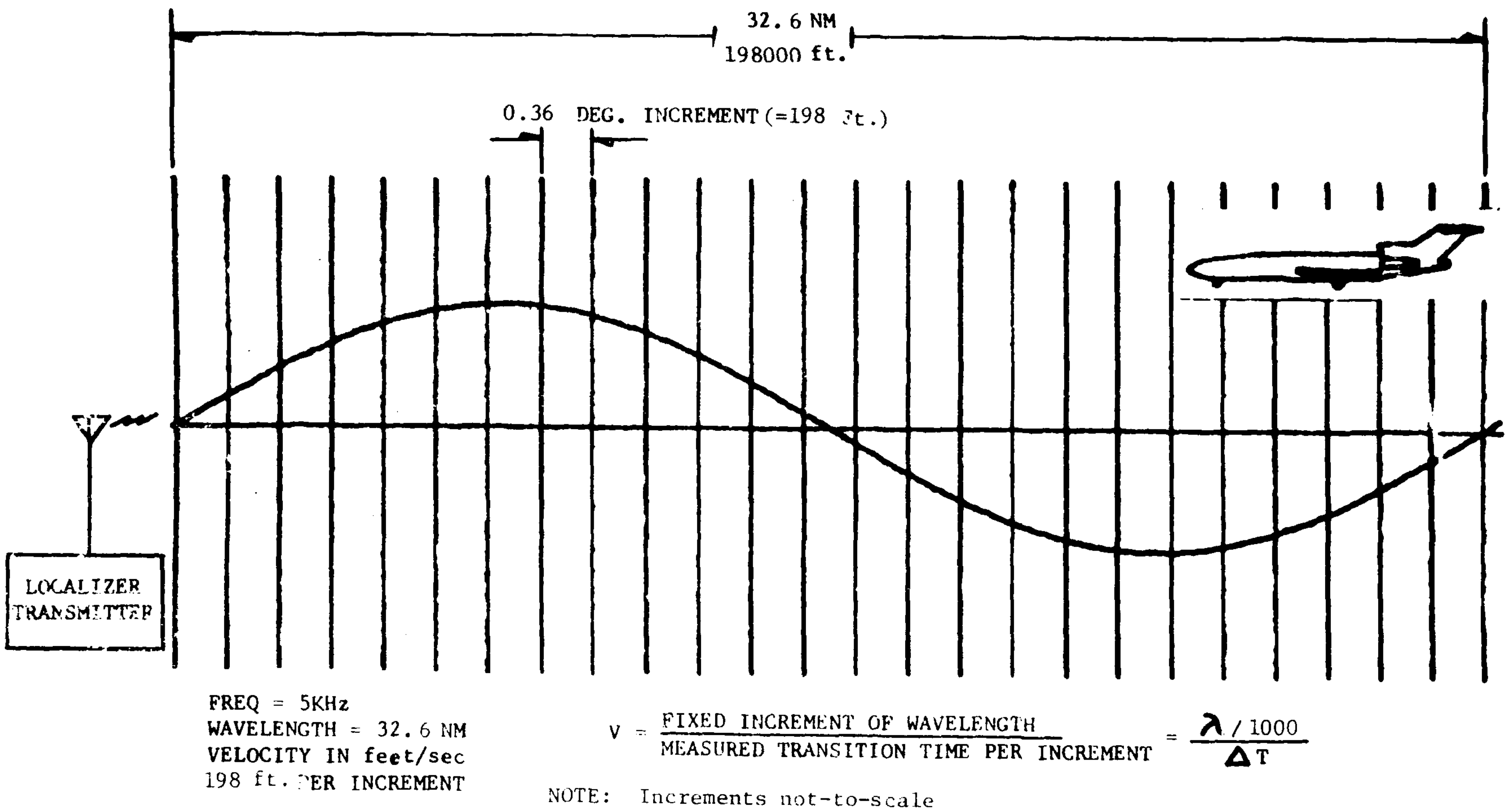


Figure 3-2. Approach and Landing Doppler Ranging System (Time Domain)

carrier frequency of the localizer, is shown by Figure 3-1. The aircraft speed and the signal wavelength are appropriate to provide a measurable beat note when the received signal is mixed with the output of an airborne clock that is synchronized with the localizer carrier frequency. While this approach is theoretically sound, it would require substantial localizer modifications to stabilize the carrier frequencies and substantial avionics modifications. The differential ranging system illustrated by figure 3-2 has been selected as the operating principle of the system described by this report. It operates on the amplitude modulated envelope of the localizer carrier, with the modulation being originated by a 5 kHz precision controlled rubidium clock source. The aircraft speed and modulation wavelength combination in this situation are not appropriate for measuring beat notes, since the beat note frequencies are on the order of a few thousandths of a Hertz. However, an equivalent measurement is made with the airborne equipment described in this report, by partitioning each wavelength into small phase increments and measuring the aircraft transition time thru each increment.

Referring now to Figure 3-3, the Instrument Landing System (ILS) localizer transmitter is amplitude modulated by an audio tone from the reference signal generator. This audio tone is derived from a precision frequency source such as a cesium or rubidium clock. The ILS localizer signal with its reference tone is received and demodulated by the ILS localizer receiver. The frequency of the demodulated tone is compared to the frequency of a tone generated by a precision frequency source in the aircraft. The frequency difference between these two tones is caused by the Doppler shift of the received and demodulated tone. This shift is a measure of the ground speed of the aircraft relative to the ILS localizer transmitter.

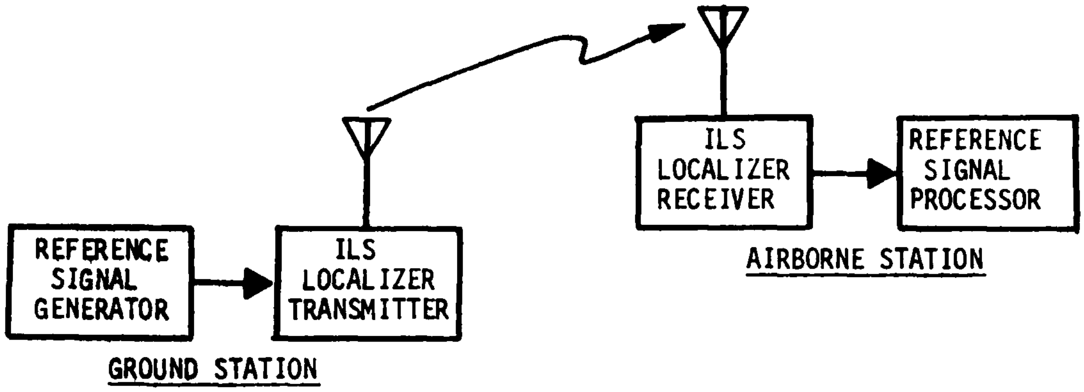


Figure 3-3. System Block Diagram.

The airborne station is shown more clearly in Figure 3-4, where the demodulated signal from the localizer receiver is filtered and converted from a sine wave to a square wave by the signal conditioner for processing by the Doppler detector. This square wave is processed with the output of the precision frequency source in the Doppler detector to generate a pulse having a period inversely proportional to the groundspeed. The period of this pulse is measured and converted to linear range rate by the Doppler processor, and displayed on a groundspeed indicator.

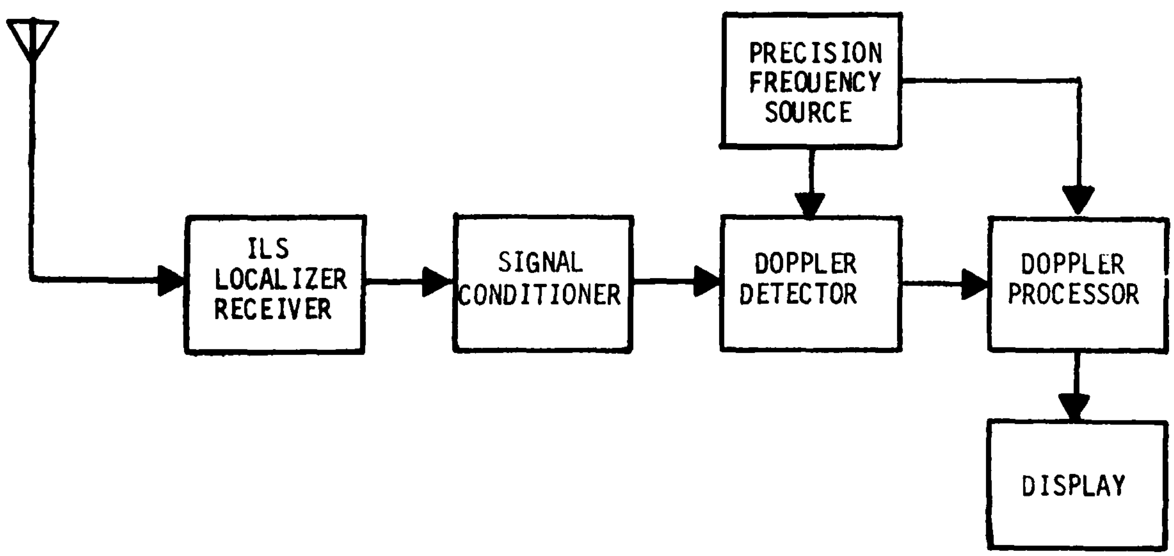


Figure 3-4. Localizer Receiver with Doppler Range-Rate Sensor.

4. SYSTEM DESCRIPTION

The ground and airborne components of this range rate sensor are considered separately in this report. The ground components that provide the precision reference tone on the ILS localizer transmitter are the responsibility of the Federal Aviation Administration. The airborne components will be provided by the users.

The system utilizes the Doppler component generated between a reference signal radiated by an ILS localizer facility and a signal obtained from a precision airborne clock. Conventional Doppler (frequency domain) techniques that measure the frequency of a Doppler beat-note cannot be utilized, because of the extremely long wave length of the reference signal (32 miles) and the relatively slow motion of a landing aircraft. Accordingly, measurements are made on a time domain basis and converted to a linear function relative to radial groundspeed. This is accomplished by measuring the amount of time it takes an aircraft to travel a fixed increment of wave length of the reference signal. A digital processor converts this period of time to a signal having a frequency that provides a ratio of one hertz per knot of radial groundspeed. A single processor using low clock frequencies provides acceptable ground speed information, but will not meet the up-date response time. Higher clock frequencies increases the response time, but groundspeed data becomes unacceptably noisy. Thus, the use of multiple processors as described by this report provides a compromise between data up-date rate and signal noise. See Figure 4-9. Two divide by "N" processor circuits are used to obtain an acceptable signal-to-noise ratio. Two additional divide by "N" processors are used to increase the data update rate. The four divide by "N" processors are sequentially updated and sampled. Two Doppler detectors are used, one for each pair of divide by "N" circuits. The Doppler signals are detected at phase quadrature which automatically provides coherent sequencing of the divide by "N" circuits. The Doppler signals are also used to program a multiplexer which insures that the latest updated data will be displayed.

4.1 Ground Components

The ground components of this sensor are the ILS localizer transmitter, the reference signal generator, and the modulator. The localizer transmitter used for this range rate function is the standard lateral guidance component of the instrument landing system. The localizer carrier is amplitude modulated by the 90 Hz and 150 Hz frequencies for lateral guidance, plus an audio identification signal. The signal format on the localizer transmitter is modified only by the addition of the reference tone modulation. The percent modulation of each of these modulations on the localizer transmitter is listed in table 4-1. It is noted and emphasized that the addition of this reference tone modulation does not detract in any manner from the primary lateral guidance function of the localizer transmitter.

TABLE 4-1.

PERCENT MODULATIONS ON LOCALIZER TRANSMITTER

FUNCTION	PERCENT MODULATION
90 Hz Guidance	20
150 Hz Guidance	20
1020 Hz Identity	10
Reference Tone	30
TOTAL	80

Referring again to figure 3-3, the 5kHz reference tone is derived from a rubidium frequency standard. The high frequency (10 MHz) of the frequency standard is digitally divided down to a 5kHz square wave. The square wave

is converted to a sine wave with passive circuitry to minimize phase noise, and applied to the automatic level control of the localizer transmitter to effect 30% amplitude modulation of the localizer carrier signal. At facilities where the transmitter has voice modulation capabilities which are no longer required, the 5kHz sine wave tone would be simply connected to the carrier modulator terminals. Since space-modulation is not used, flight inspection of the reference signal is not required and monitoring of the 5kHz signal would be a simple go-no go alarm operation.

The range rate ground equipment for these tests utilized a standard 7 inch rack panel.

4.2 Airborne Components

The 5kHz tone from the localizer is obtained from the audio section of a conventional navigation receiver for airborne processing. With some receivers, the tone is available at the audio output terminal. With receivers that utilize audio band pass filtering, the tone is obtained ahead of the filter. No other connections or changes to the receiver are required. A block diagram of the major airborne components is shown by Figure 4-1.

4.2.1 Precision Frequency Source

The precision frequency source for the airborne equipment can be either cesium or rubidium clocks, or the less precise but adequate oven control crystal clock. While the crystal clock would cost considerably less, it would require periodic calibration that could offset its cost advantage. The precision frequency source includes a digital frequency divider to convert the clock frequency to those frequencies required by the Doppler detectors and processors.

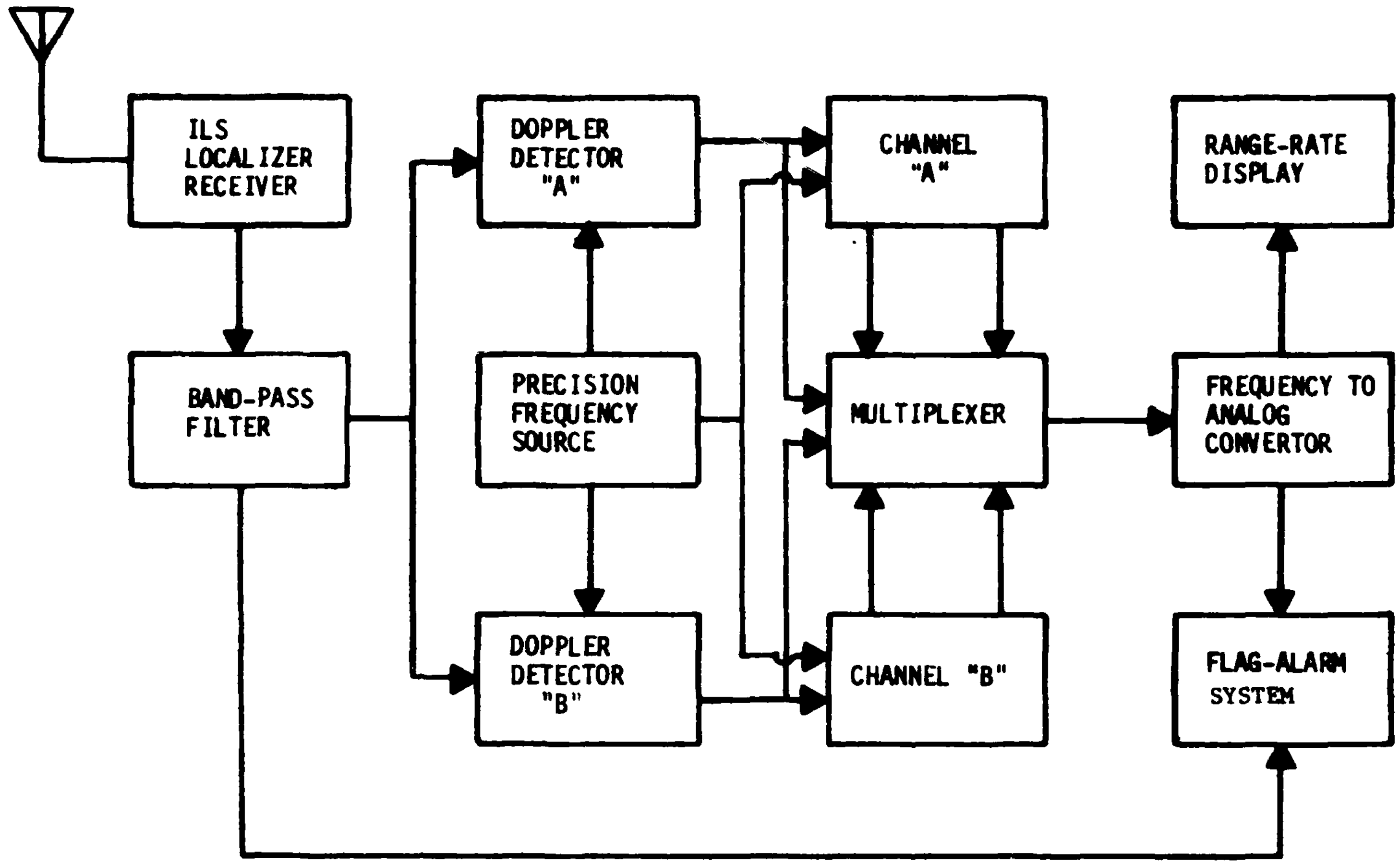


Figure 4-1. Localizer Range-Rate Sensor.

The accuracies of the clocks in knots per unit time, considered for both the airborne and ground components, are shown by Table 4-2. Rubidium clocks were selected for the equipment described by this report.

TABLE 4-2.

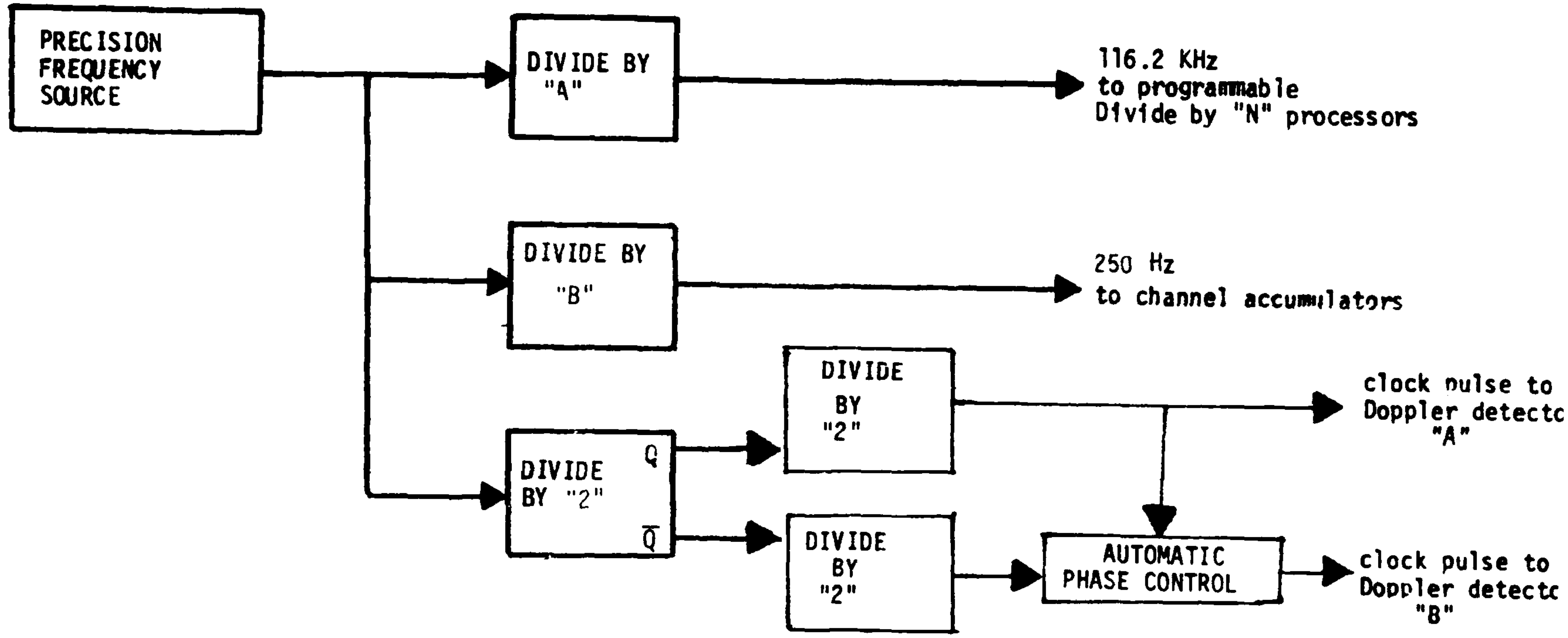
CLOCK ACCURACIES

GROUND CLOCK	AIRBORNE CLOCK QUARTZ	RUBIDIUM	CESIUM
Quartz	4.08 kt/week	2.04 kt/week	2.04 kt/week
Rubidium	2.04 kt/week	0.14 kt/year	0.07 kt/year
Cesium	2.04 kt/week	0.07 kt/year	-

These values were obtained from Hewlett-Packard and Efratom equipment specifications. The ground facility will use the rubidium frequency standard. The clock-divider network to provide the precision frequencies required by the airborne processors, accumulators, and detectors, is shown by Figure 4-2.

4.2.2 Signal Conditioner.

As illustrated in figure 4- 1, the 5kHz tone is conditioned with a bandpass filter having a high input impedence to prevent derogation of the aircraft receiver performance. The output of the bandpass filter is a 5kHz square wave that is applied to the Doppler detectors. Figure 4-3, illustrates the type of filter used to obtain engineering test data. It is basically a phase locked loop (PLL) circuit employing a special differential filter in the loop feedback network. Two mixers use complementary signals which are derived from the divide by "N" network to provide inversely proportional analog voltages. With reference to Figure 4-4, these analog voltages are developed across resistors R_1 and R_2 of the L-R integrator networks. These resistors are also part of a differentiating network effected by capacitor C.



NOTES: (1) See Figure 4-5 for clock waveforms.
(2) Automatic Phase Control maintains correct relative phase relationships.

Figure 4-2. Clock/Divider Network.

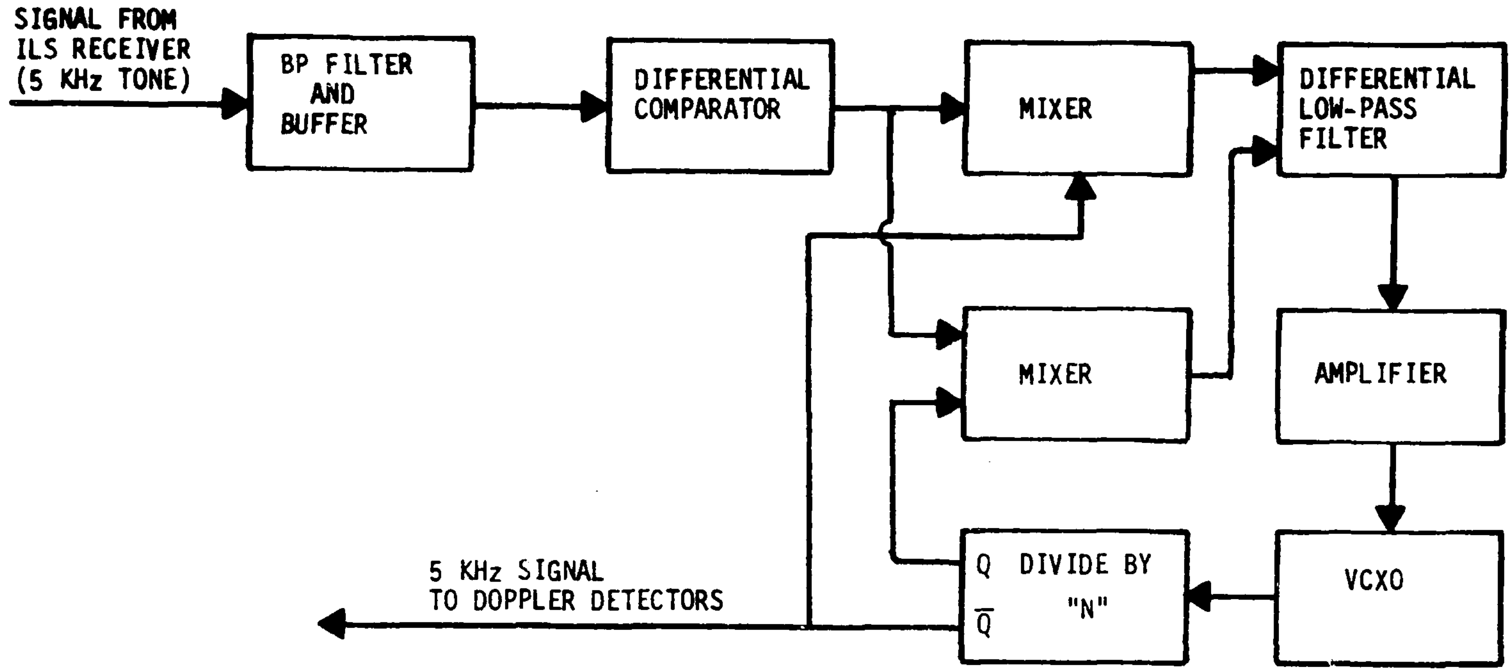


Figure 4-3. Signal Conditioner.

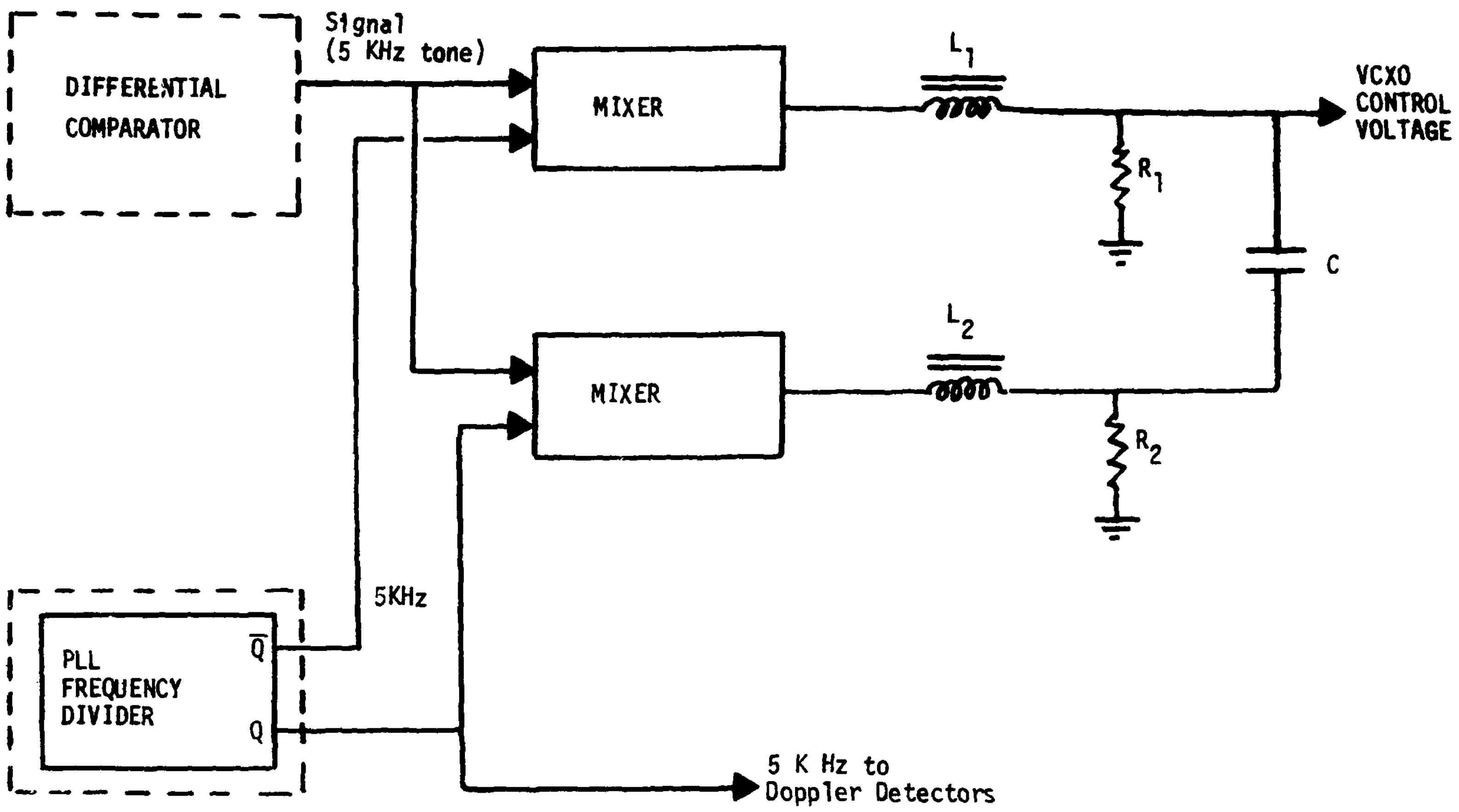


Figure 4-4. Differential Low-Pass Filter.

Thus, the integrators and differentiator utilize common resistors to perform both functions. The differentiating portion of the network is only active in the presence of noise and provides a high degree of noise rejection.

4.2.3 Doppler Detectors

Two separate Doppler detectors are utilized to increase the data up-date rate. This is accomplished by applying the clock frequencies at a phase quadrature relationship between detectors. This phase quadrature relation is obtained as shown by Figure 4-5.

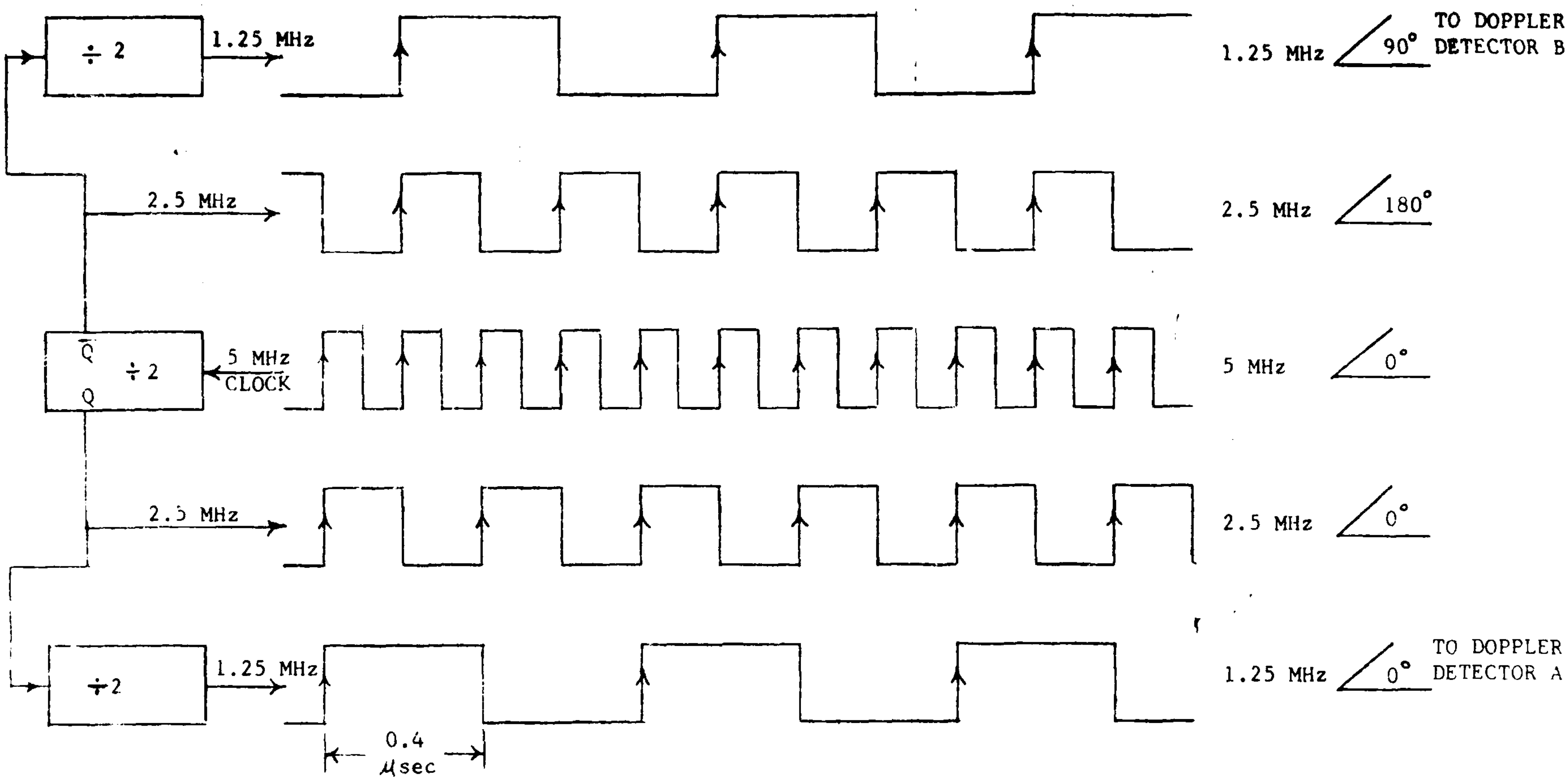
The detectors can be either digital as in Figure 4-6, or analog as in Figure 4-7. The digital configuration was used during the flight tests described by this report, with all test results meeting the accuracy and response time requirements for wind shear avionics. The analog configuration, now undergoing flight tests, has demonstrated a significant noise reduction as compared to the digital configuration. However, the analog director requires a frequency multiplier to multiply the 5KHz signal up to the 1.25MHz clock frequency. The digital detector does not require a frequency multiplier, although a PLL multiplier circuit was used to provide filtering of the 5kHz signal.

Referring now to the Figure 4-6 digital Doppler detector, a monostable circuit converts the 5 KHz square wave to a 5 KHz pulse. This pulse and the clock pulse are applied to a coincidence detector which upon coincidence causes the flip-flop circuit to change state. This in turn causes the phase shifter to invert the clock pulse which is then shifted an additional 90^o before being applied to the coincidence detector. This action is repeated every time the 5 KHz pulse becomes coincident with a clock pulse. Since the clock signal is a 1.25 MHz square wave having a total period of 0.8 microsecond, coincidence will occur every time the 5 KHz reference pulse advances 0.72 electrical degrees (0.40 usec) due to motion of the

aircraft. Thus the periodic rate of coincidence is related to aircraft radial velocity. The Doppler signal is obtained by detecting the clock signal phase relationship between the input and output terminals of the 180 degree phase shifter.

This detection is accomplished by two mixers operating in a complementary fashion which provides out-of-phase signals required for the differential comparator. The output of the comparator provides a square wave Doppler signal. Since the clock pulses applied to the detectors are at phase-quadrature, the square wave Doppler pulses of each detector will have a quadrature relationship. By utilizing the positive-going and negative-going edges of the Doppler pulses, the sensor will be up-dated each 0.36 degree (198 ft.) increment of phase change of the 5 kHz reference signal.

The analog detector, shown by Figure 4-7, differs from the digital detector, in that the 1.25 MHz signal is derived by a PLL frequency multiplier that is locked to the 5 kHz modulation on the received signal. This 1.25 MHz signal is then mixed with a 1.25 MHz clock signal which produces the Doppler signals applied to the differential comparator.



CLOCK DIVIDER WAVEFORMS

FIGURE 4-5

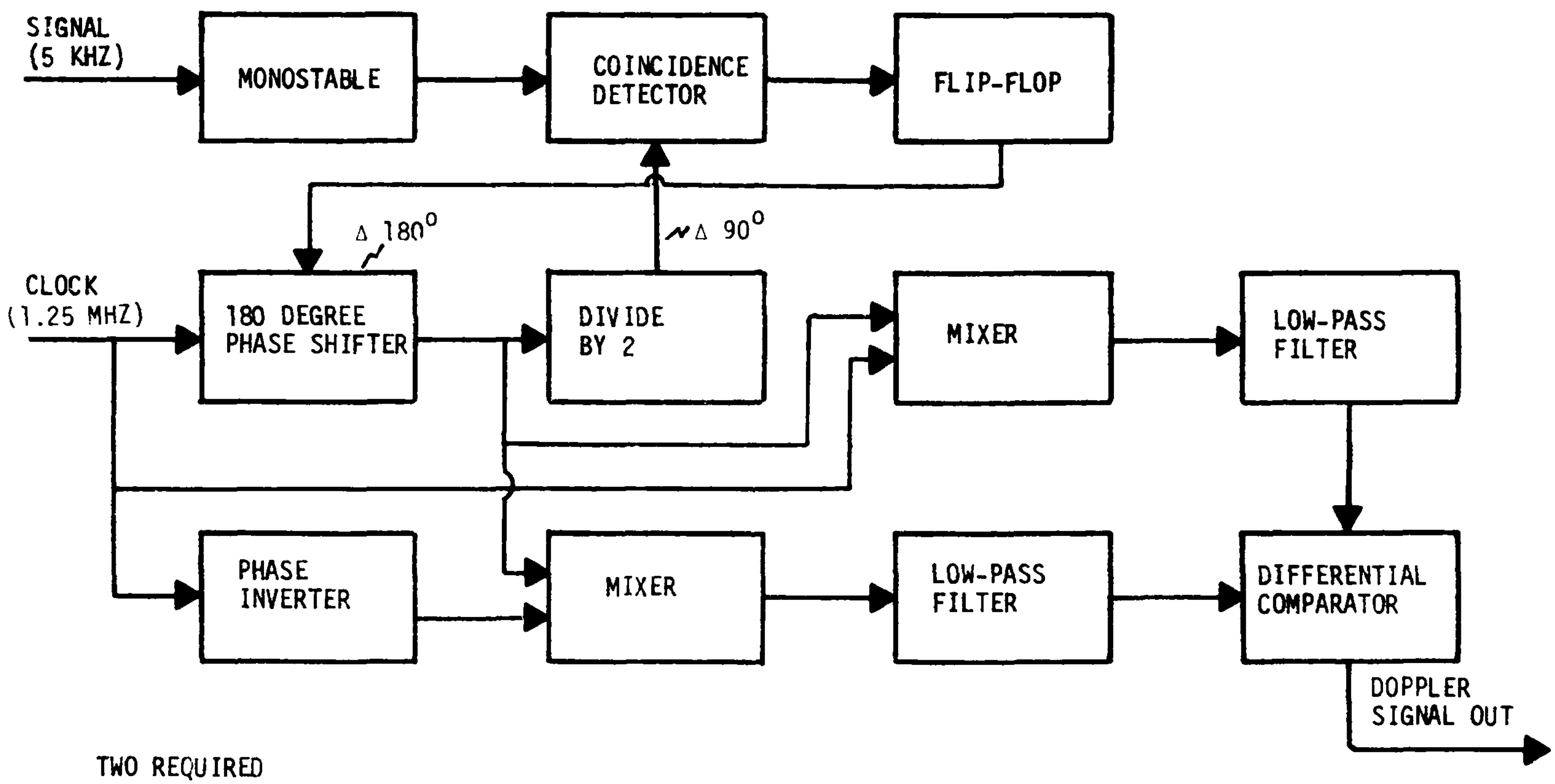


Figure 4-6. Digital Doppler Detector.

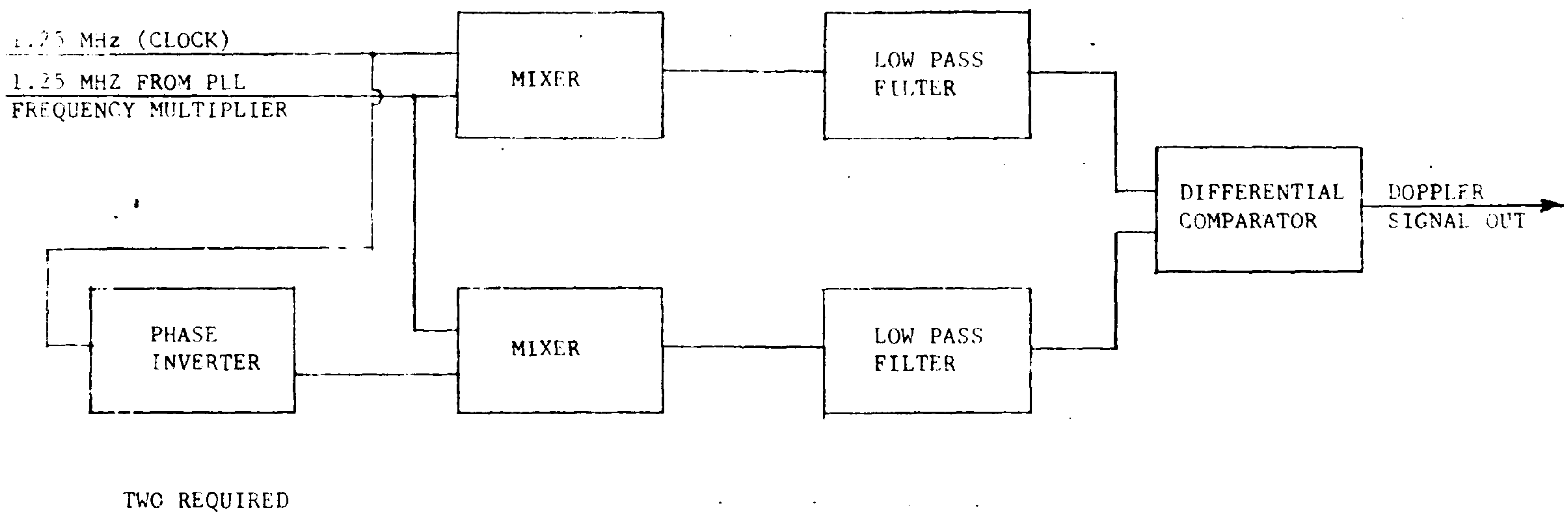


FIGURE 4-7.ANALOG DOPPLER DETECTOR

4.2.4 Doppler Processor.

With reference to Figure 4-8, the output of each detector is applied to separate channels for processing. Each channel contains two processors. All four processors are identical except that one processor in each channel operates on positive-going Doppler signals. The other processor in each channel operates on negative-going Doppler signals. Since the Doppler signals are applied at phase-quadrature to each channel, the processors will automatically be sequenced over the Doppler period. For example, if the Doppler period is four seconds per processor, the up-dating of each processor is evenly staggered over this period, thus providing new groundspeed information once every second. This situation is illustrated by Figure 4-9 using actual time interval values of the flight tested system. That figure shows a range rate step function, the measurement characteristics, and the filtered display. It is emphasized that the step function represents a worse case situation and that the aircraft mass restricts the velocity change to only a few knots per second. Accordingly, the actual error inherent in the measurement system caused by accelerations is considerably less than that shown by the illustrated example. Note that after the actual range rate change, the measured value can remain unchanged for one full update period, i.e., for 0.777 sec. The measured value approaches the actual value as each processor is sequenced, and the measured value equals the actual value after 4 updates, i.e., 0.777 X 4 = 3.1 seconds. This response capability fully meets wind shear avionics requirements.

One of the four identical processors is illustrated by Figure 4-10. The square wave Doppler pulse is applied to a monstable circuit which is

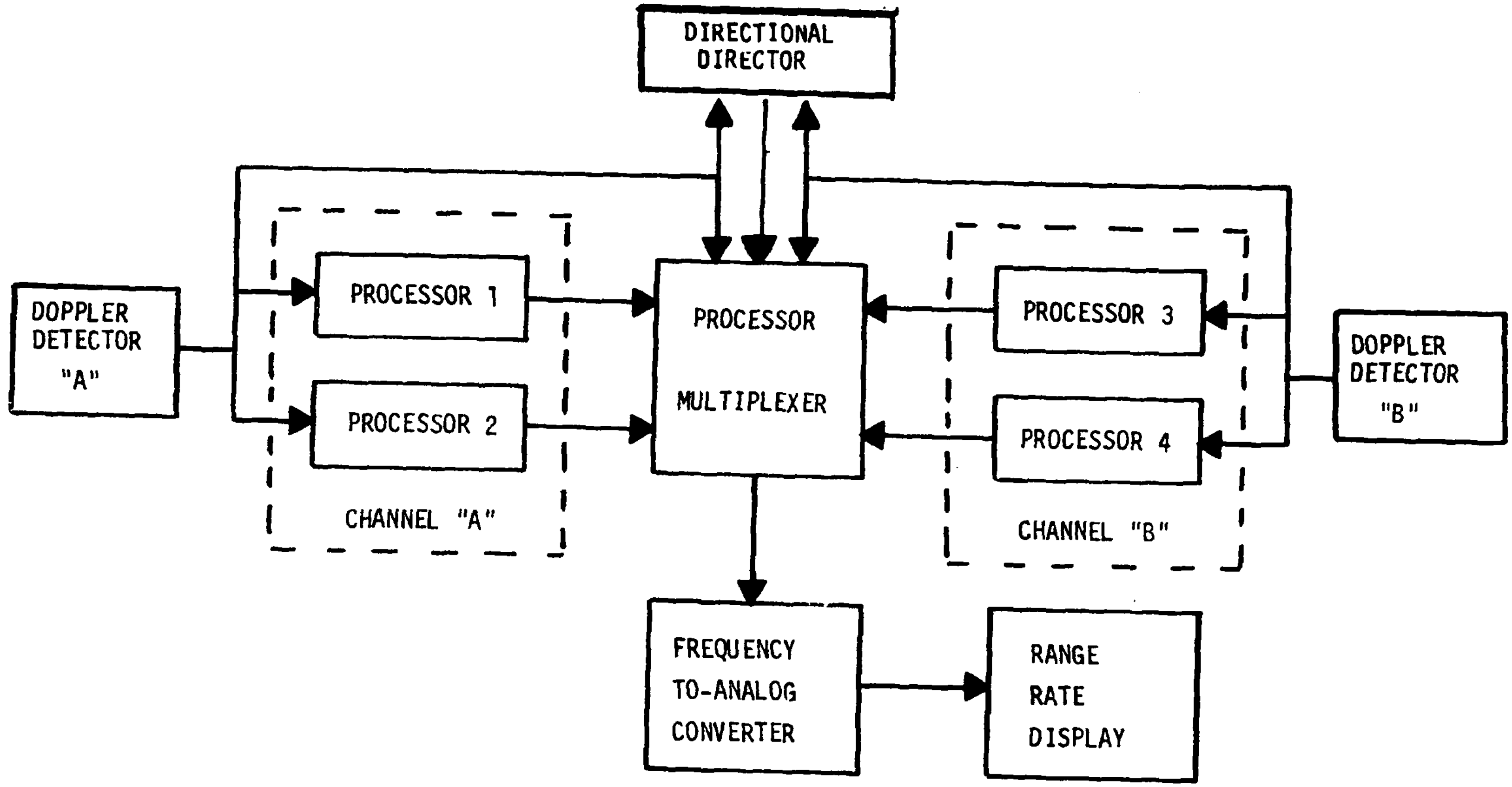


Figure 4-8. Range-Rate Channel Multiplexer.

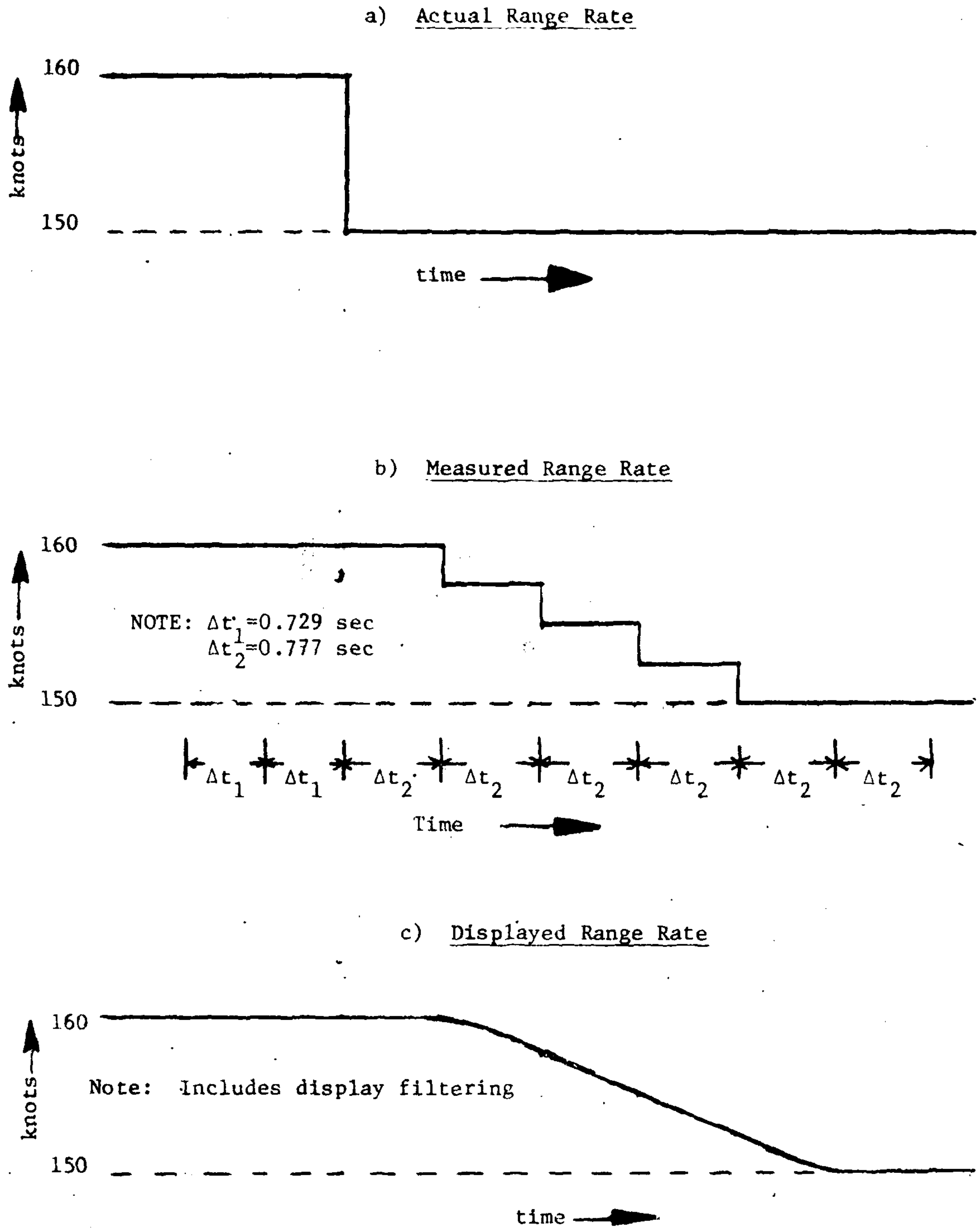
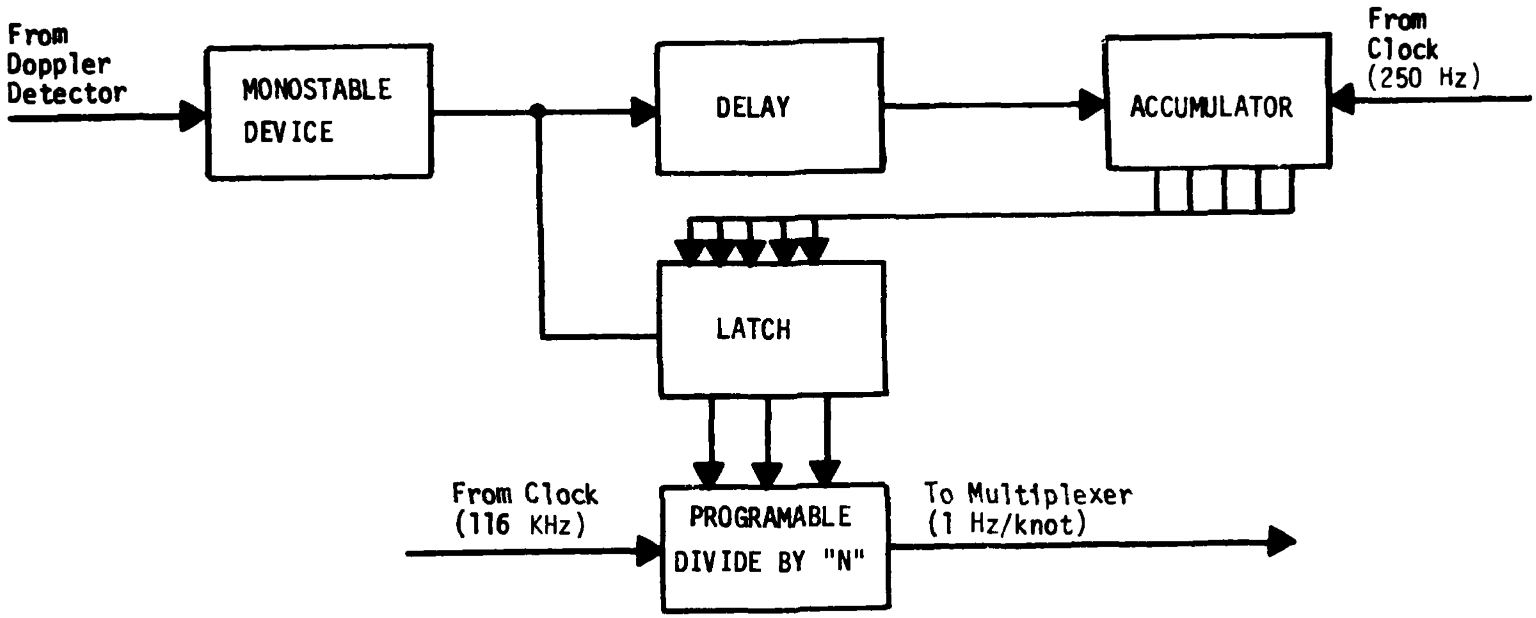


Figure 4-9. Display Response to Range Rate Step Function



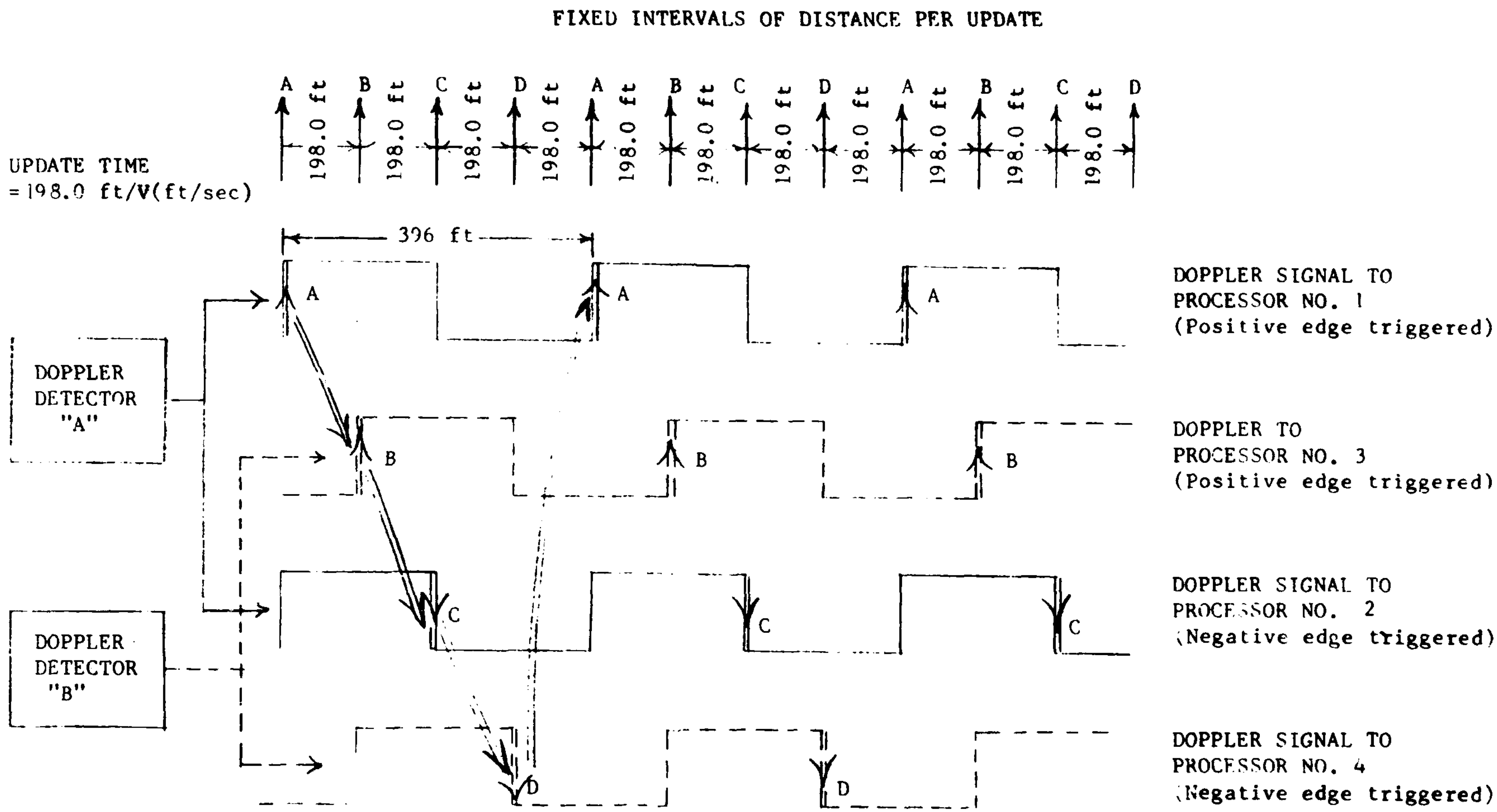
Note: This drawing shows one of four required Doppler processors

Figure 4-10 Range-Rate Processor

pre-conditioned to operate on a positive-going or a negative-going voltage as previously mentioned. The output pulse of the monostable is first applied to the latch circuit. The latch will transfer the number of clock pluses accumulated by the accumulator to the divide by "N" circuit. The divide by "N" circuit will divide the 116 kHz clock frequency by the number of accumulated pulses or counts latched. The monostable output pulse is delayed before resetting the accumulator for a new count to insure that a valid count has been transferred to the divide by "N" circuit. This process is repeated on each positive or negative edge of the Doppler pulse. The clock frequencies applied to the accumulator and divide by "N" circuit are selected to produce an output frequency that provides 1 Hz for each knot of radial groundspeed. For example, at a radial groundspeed of 116 kts., the detected Doppler period would be four seconds. This would allow the accumulator to accumulate 1000 pulses during each 4 seconds at the 250 Hz pulse rate. The number 1000 would be latched into the divide by "N" circuit. Accordingly, 116 kHz divided by 1000 equals 116 Hz which corresponds to 116 knots.

4.2.5 Processor Multiplexer.

The output frequency of each processor is directly related to ground speed with the up-dating of each processor being automatically sequenced by the nature of the two quadrature Doppler signals. This sequencing of the processors requires coherent multiplexing of the output signals to retrieve the most recently up-dated data. The multiplexer is also programmed by the quadrature phase Doppler signals of each channel and accordingly, the output frequency of the multiplexer represents the latest groundspeed information. This update sequence is shown by Figure 4-11 and the relation of range rate vs. update time by Figure 4-12. The update



DOPPLER WAVEFORMS AND PROCESSOR UP-DATE CHARACTERISTICS

FIGURE 4-11

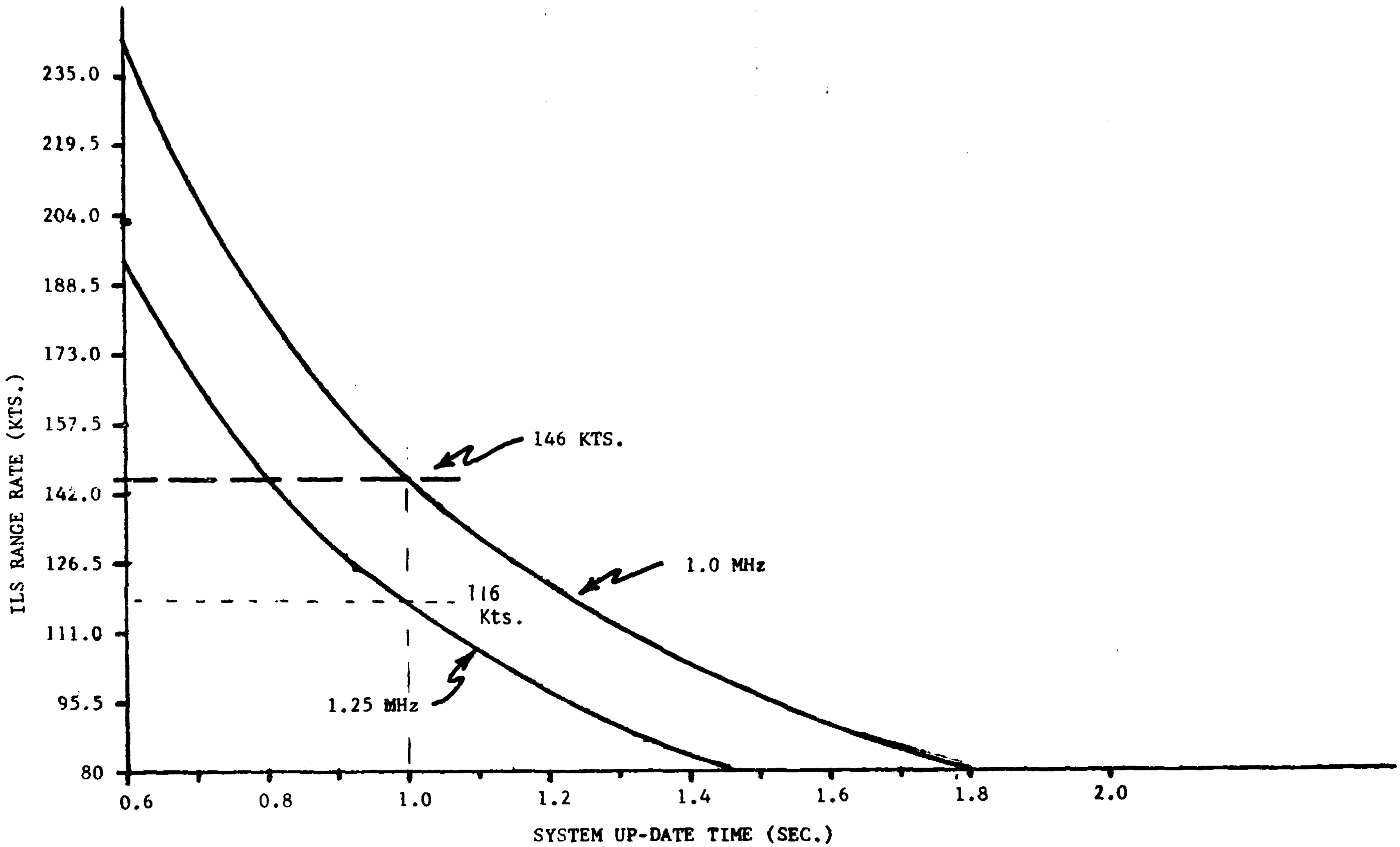


Figure 4-12. Range Rate Versus Up-Date Time

time also is a function of the clock frequency, and is shown in Figure 4-12 for clock frequencies of 1 MHz and 1.25 MHz. The 1.25 MHz value is used for the system described by this report. The output frequency can be displayed on a digital counter. However, the frequency is converted to an analog signal which can more readily be filtered. The filtered analog signal is applied to the range-rate display. The analog signal is calibrated to provide a linear voltage of 10 millivolts per knot of groundspeed.

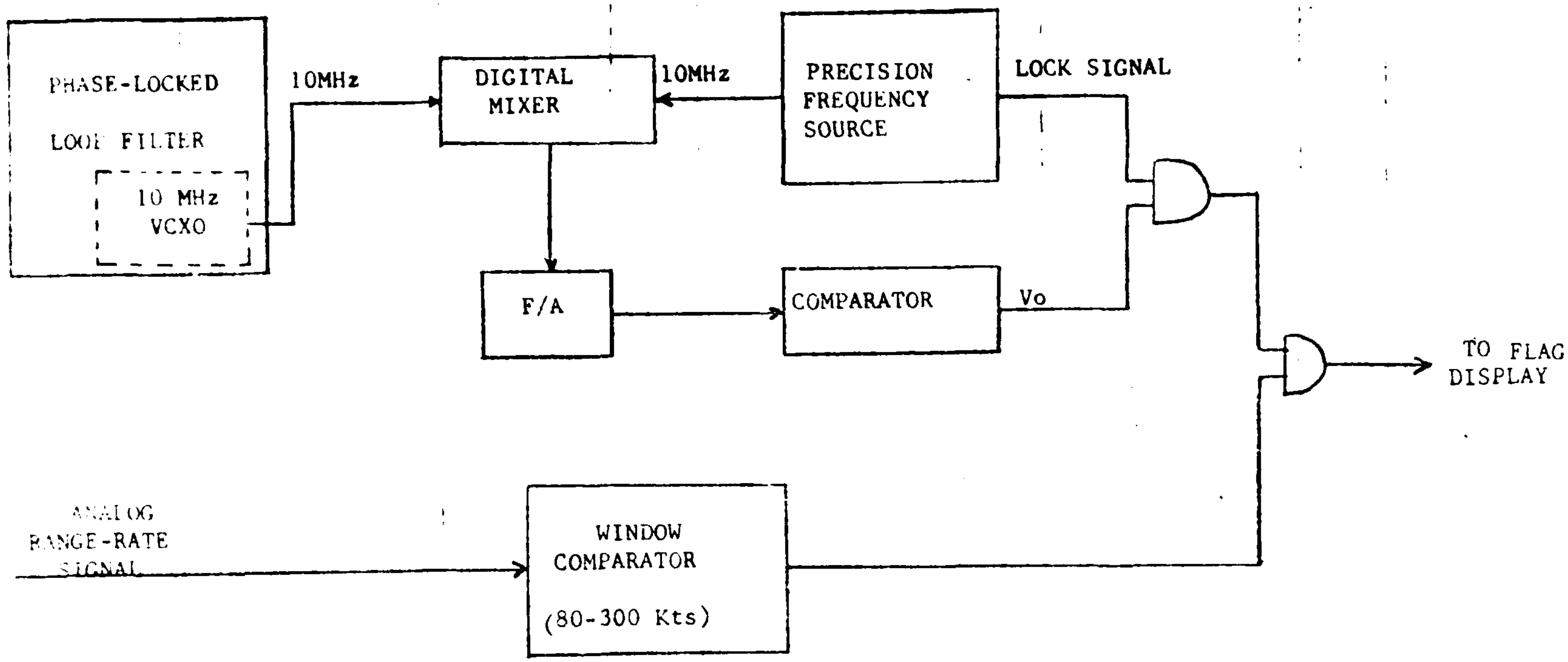
It should be noted that when approaching the localizer facility the 5kHz reference signal is advancing in phase relative to the airborne clock. When departing the facility, the 5kHz reference signal is retarding in phase relative to the airborne clock. Accordingly, a directional phase detector is required to assure coherent multiplex performance. The directional phase detector can also provide to-from information for display.

4.2.6 Sensor Flag System

The sensor flag system is designed to monitor significant parameters in order to alert the flight crew of any equipment malfunctions, as illustrated by Figure 4-13.

The PLL filter utilizes a 10 MHz voltage controlled crystal oscillator (VCXO) which multiplies the Doppler component of the 5 kHz reference signal 2000 times. Accordingly, this small increase in the frequency of the 10 MHz PLL signal can be detected by mixing the PLL 10 MHz signal with the airborne precision frequency source. This beat frequency in the order of 2 to 3 hertz is applied to a frequency to analog convertor. The D.C. voltage out of this convertor is proportional to the input frequency. Upon loss of the 5 KHz signal or if for any reason the loop is not locked, the 10 MHz VCXO frequency will change by 1 KHz or more, thus causing a large F/A output voltage. The comparator will sense this change in voltage and its output will drop to zero volts, thus causing the output V_o of the associated "and" gate to go to zero volts. This condition causes a flag alarm. A flag alarm would also be caused if the lock signal of the precision frequency source should to to zero, indicating a clock component failure.

A window comparator is utilized to indirectly monitor other parameters that could affect system performance. Failure of any one of the doppler processors, groundspeed frequency to voltage convertor, channel multiplexer and other associated circuitry would cause a radical change in groundspeed. Accordingly, by monitoring the analog range rate signal with a window comparator adjusted to detect speeds outside specified limits, failure of any one of these parameters also would cause an alarm.



PARAMETERS MONITORED

1- [illegible] Reference Signal
2- [illegible]
3- Precision Frequency Source
4- F/A Convertor (Shown in Figure 4-8)
5- Doppler Processors

Figure 4- 13. Sensor Flag System

4.3 Alternate Approaches

Alternate approaches using Doppler range rate were considered during this program. One approach considered controlling the carrier frequency of the localizer with a precision clock, and mixing the received carrier with a frequency synthesized by the airborne clock to measure the Doppler frequency. While this method had the merit of simplicity, it would require substantial modifications to the airborne receiver and this was discarded. Another approach considered was to provide a modulation on the carrier with a frequency signature that identified the carrier frequency drift. When the receiver carrier is mixed with the aircraft frequency standard, the error caused by carrier drift is corrected by the information provided by the modulation. This approach was successfully flight tested, and had considerable merit. However, it was discarded in favor of the system described by this report because of the cost effective advantages of the described system.

Several techniques and circuit configurations were tested with the selected approach, as listed below. The asterisked techniques were those used in the final equipment that was fabricated and tested during this program and described in this report:

a) Precision Frequency Source

   Quartz

   Rubidum*

b) Localizer Receiver

   Vacuum Tube

   Solid State*

c) Signal Conditioner

Phase locked loop*

Mechanical filter

Ceramic Filter

Digital Filter

d) Doppler Detector

Synchronous

Non-Synchronous

Freq. Multiplier

Sample & Hold

Balanced Mixer

Digital Phase Shift*

Frequency Off-Set

e) Doppler Processor

Multiplying D/A

Programmable Divide by "N"*

Slope Integration

f) Display

Analog

Digital

Hybrid*

4.4 Multipath Considerations

This localizer range rate measurement system has inherent and significant multipath resistant characteristics.

The multpath resistant features include:

(a) The localizer antenna pattern is highly directional, with the peak of its main lobe in the on-course direction, as illustrated by Figure 4-14. All localizer facilities that will be provided with this range rate function already will have been certified for the primary lateral guidance function, which includes proper resistance to multipath that could otherwise derrogate system performance. It is important to note that the range rate system does not use space modulation, and thus the signal will be even more

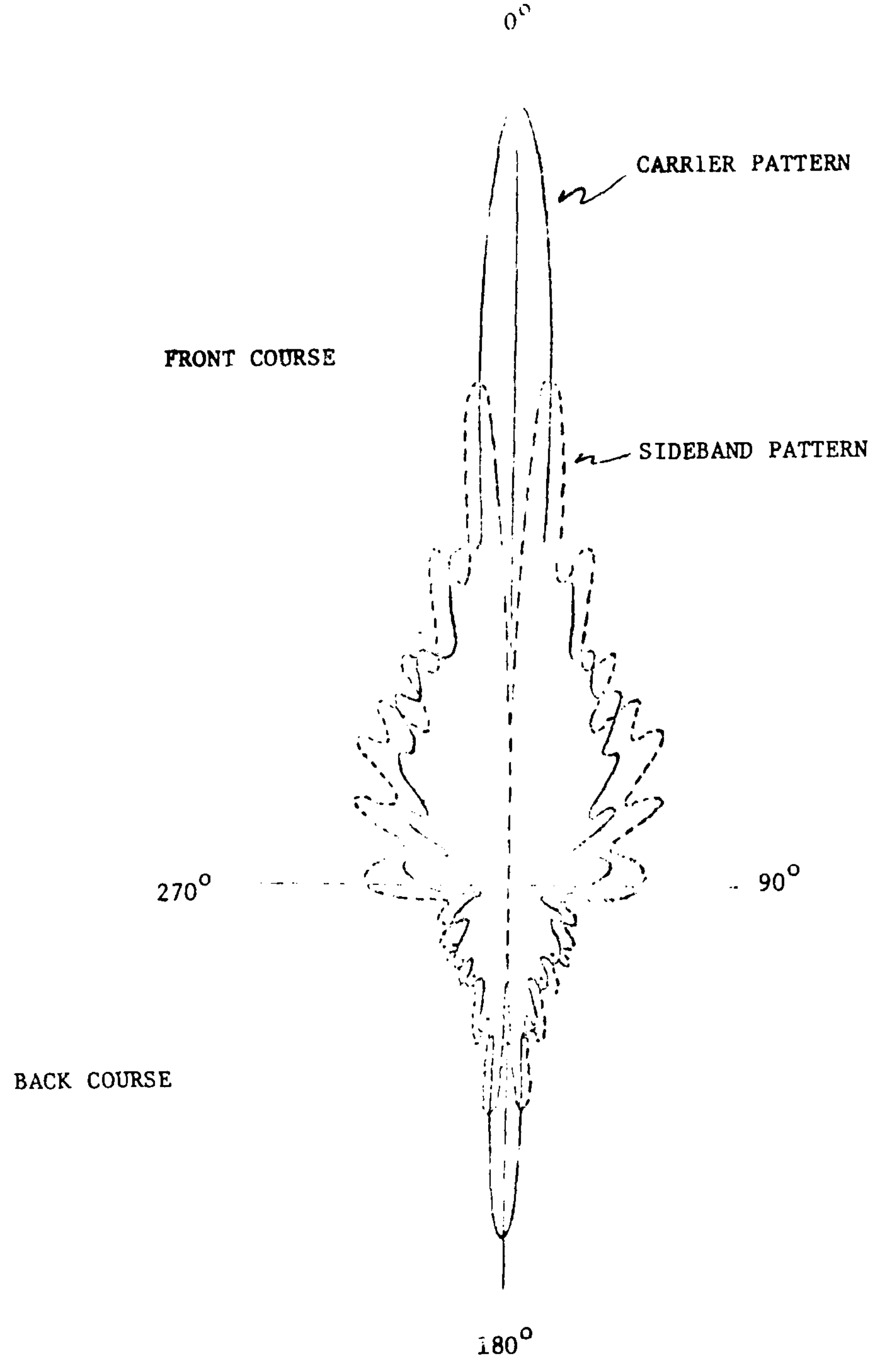


Figure 4-14. Antenna Patterns from V-Ring Localizer Array

resistant to multipath than the lateral guidance signal. Its energy radiated in the direction of the reflecting surface will always be less than or equal to the direct signal to the localizer receiver antenna. However, the lateral guidance signal is radiated by the sideband antenna, which nulls on-course and is maximum at about 10 degrees on both sides of on-course centerline. Thus, the multipath-to-direct signal ratio for the range rate signal always will be considerably less than for the azimuth signal. It is evident that the certified localizer facility will assure proper multipath protection of the range rate system.

b) The range rate error cannot be greater than $v(1-\cos\theta)$, where v is the range rate when the aircraft is on-course, and θ is the angle between the flight path and the line connecting the aircraft and the reflecting object. Note that for $\theta \leq 11$ degrees, the range rate error, due to multipath would be less than 2 percent, even under worst case conditions where the direct signal is shadowed and only the multipath signal arrives at the localizer receiver.

c) A high amplitude, low scalloping frequency, multipath environment can effect systems that derive range rate by differentiating techniques, considerably more than one-way Doppler derived range rate. When the scalloping frequency is too low for effective filtering (since filtering is limited by response time requirements), the differentiating process that establishes range rate could introduce a significant error.

Accordingly, this one-way Doppler range rate system has an inherent significant resistance to multipath environments.

5. FLIGHT TEST PROGRAM

The localizer range rate measurement system, configured as described by Section 4 of this report, was flight tested at Andrews AFB, Md. The facilities, flight test profiles, and test results are described in this Section.

5.1 FACILITIES

The localizer modulated by the precision frequency source was a small (30 ft.) aperture, 6 dipole array mobile unit with a 6 degree course width, operating at 109.1 MHz. The power at the transmitter output terminals was 10 watts. The small aperture provided a carrier antenna beamwidth that was considerably wider than that of the Andrews AFB commissioned localizer facilities, and thus was more susceptable to multipath than the commissioned facility. However, multipath errors were not evident during these tests, except during deliberate localizer overflights by "other" aircraft.

The localizer antenna that transmitted the range rate signal was located at Andrews AFB, 500 ft. beyond the overrun region of runway 19L and 200 ft. offset from runway centerline. All runs were made on the localizer back course, i.e., towards runway 1R, and towards an "imaginary" runway approach threshold located on the back course 9000 ft. from the localizer antenna. The DME used for range measurements was located alongside runway 1R, about 5200 ft. from the localizer antenna. The locations of these facilities are shown by Figure 5-1. A photograph of the localizer range rate ground equipment is illustrated by Figure 5-2.

5.2 FLIGHT TEST PROFILES

All flight test data obtained at Andrews AFB utilized a military KC135 aircraft, which is the military equivalent of the Boeing 707 commercial aircraft. The test aircraft was equipped with a Litton Model LTN-72R Inertial

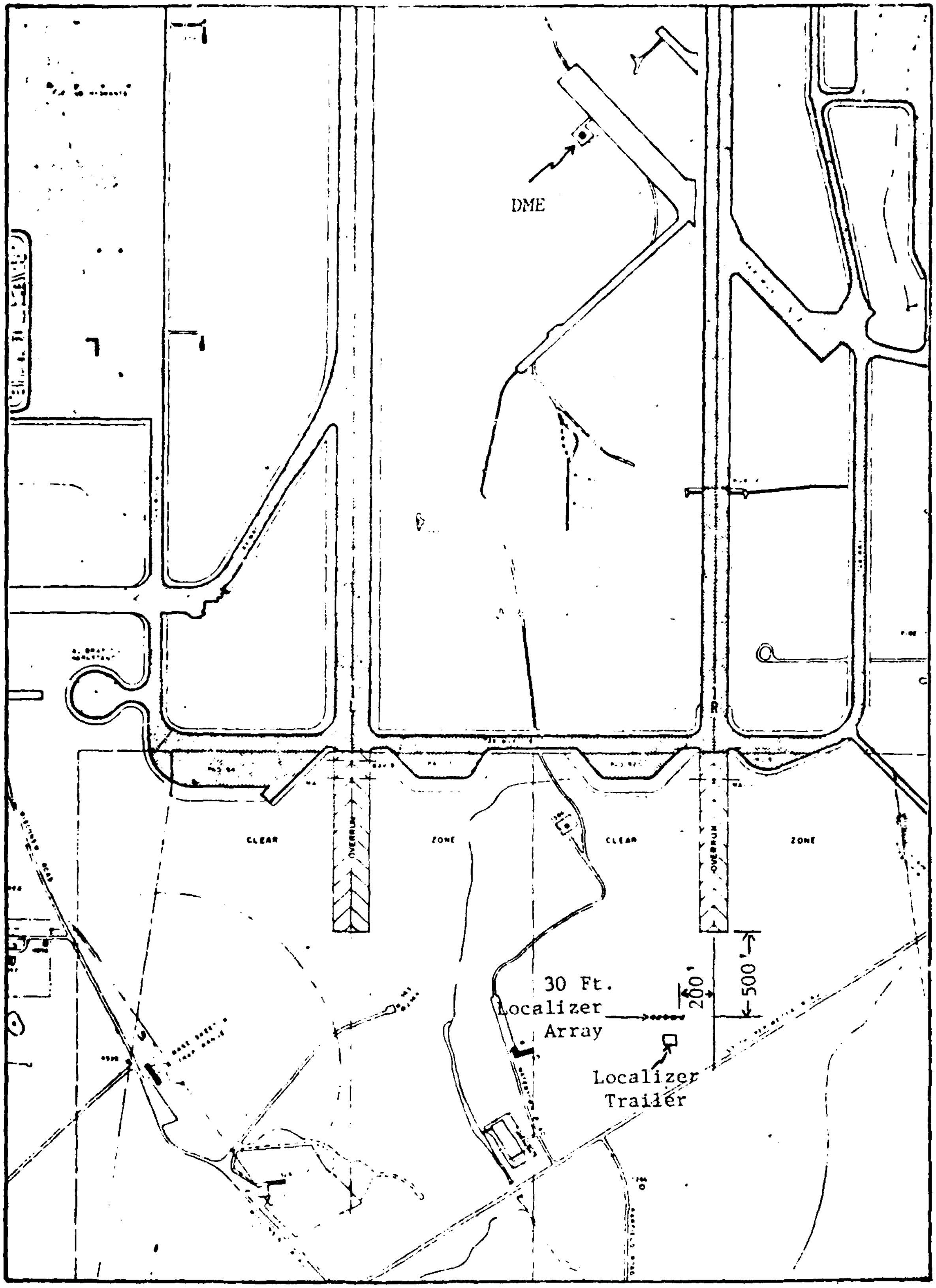


Figure 5-1. Map of Test Site at Andrews Air Force Base

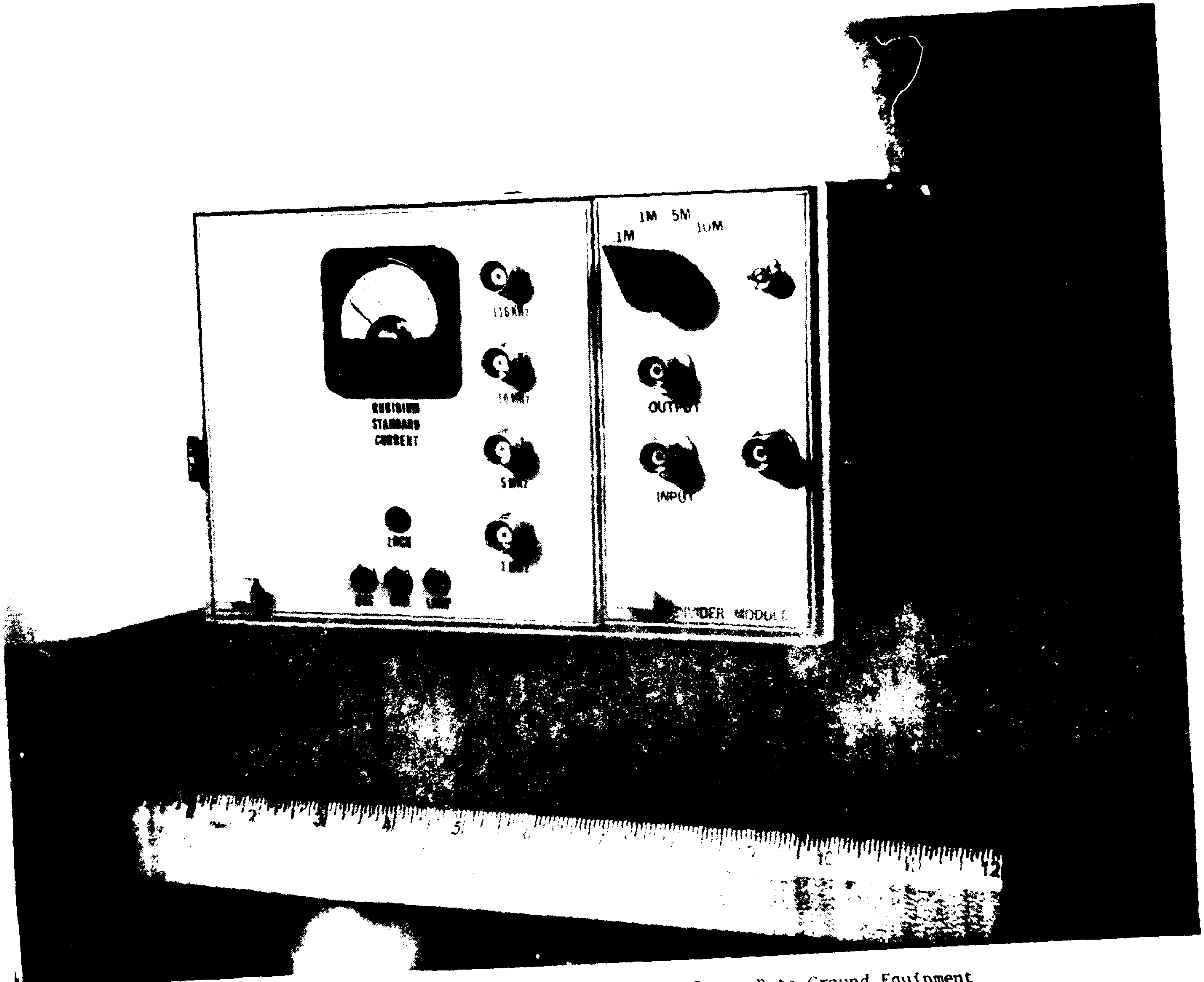


Figure 5-2. Photograph of Localizer Range Rate Ground Equipment

Navigation System. A synchro to DC analog converter was used to provide a continuous INS analog reference groundspeed signal. The INS groundspeed and the localizer range rate signals were recorded simultaneously on a strip chart. A photograph of the flight test brassboard equipment is shown by Figure 5-3. A photograph of the demonstration flight test panel is shown in Figure 5-4. Observe that the panel design provides for the ILS (localizer) ground speed pointer being vertically aligned with the INS ground speed pointer when the system error is zero. The airspeed pointer also is vertically aligned with the other two pointers when there is zero wind at flight altitude.

The early flights, shown by Figure 5-5 and 5-6, were made on the back course of the mobile localizer sited as shown in Figure 5-1. While front course approaches were preferred because of the better signals radiated in that direction, traffic control constraints at that time precluded front course approaches. The back course signals were at least 8dB below those of the front course. Lateral guidance during these range rate runs was obtained from the localizer signal, and vertical guidance from the Andrews GCA equipment. The aircraft was stabilized on its approach path about 7 n.m. from approach threshold. The four approaches shown by Figure 5-5 were made under the following conditions.

Run 1: Two dots high on glideslope

Run 2: Two dots left on localizer course

Run 3: Standard approach

Run 4: Standard approach, with programmed localizer overflight by "other" aircraft

The actual flight test recordings of standard approaches on the back course are shown by Figures 6a and 6b. Two front course approaches are shown by Figures 7a and 7b.

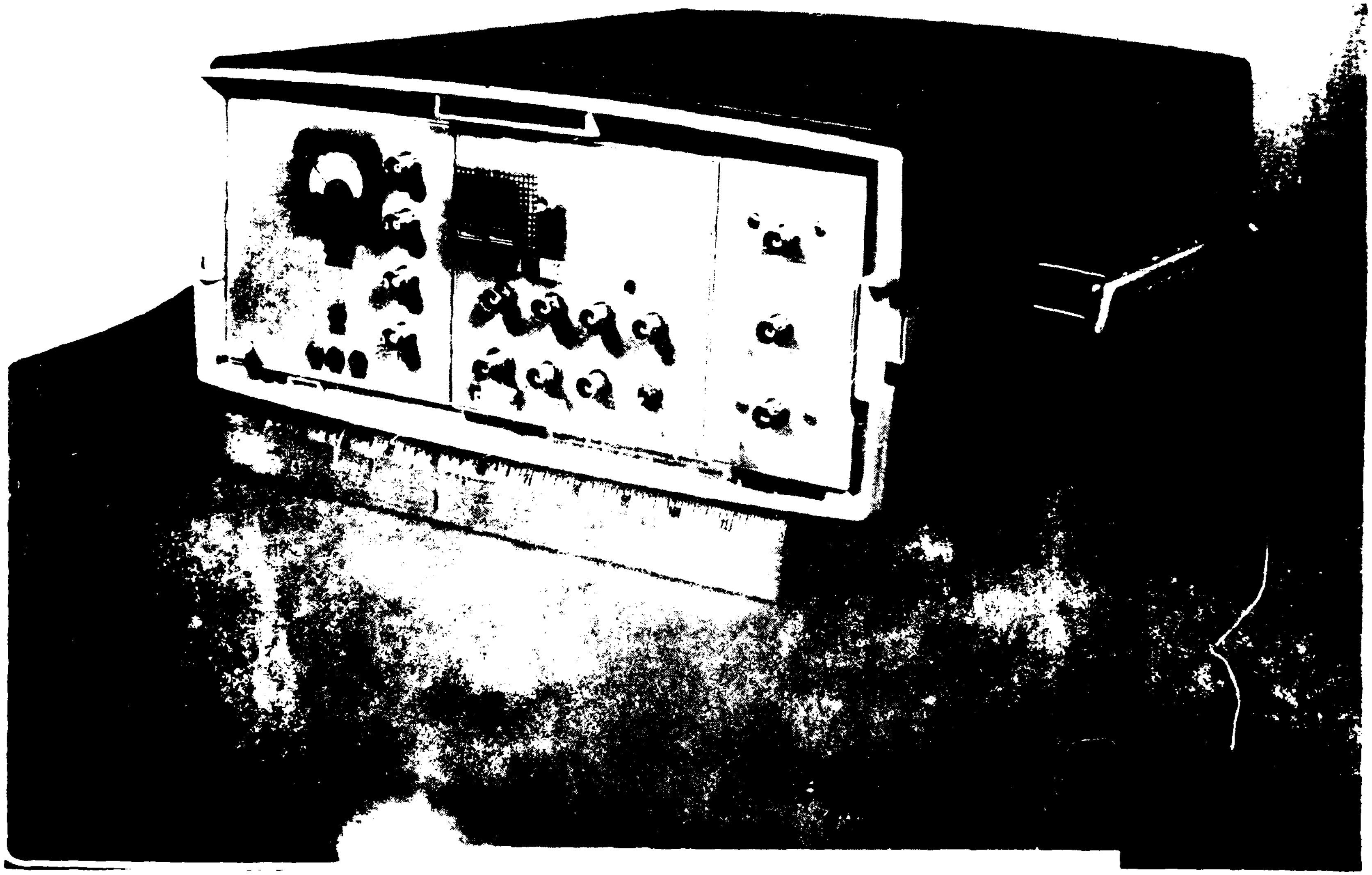


Figure 5-3. Photograph of Flight Test Brassboard Equipment

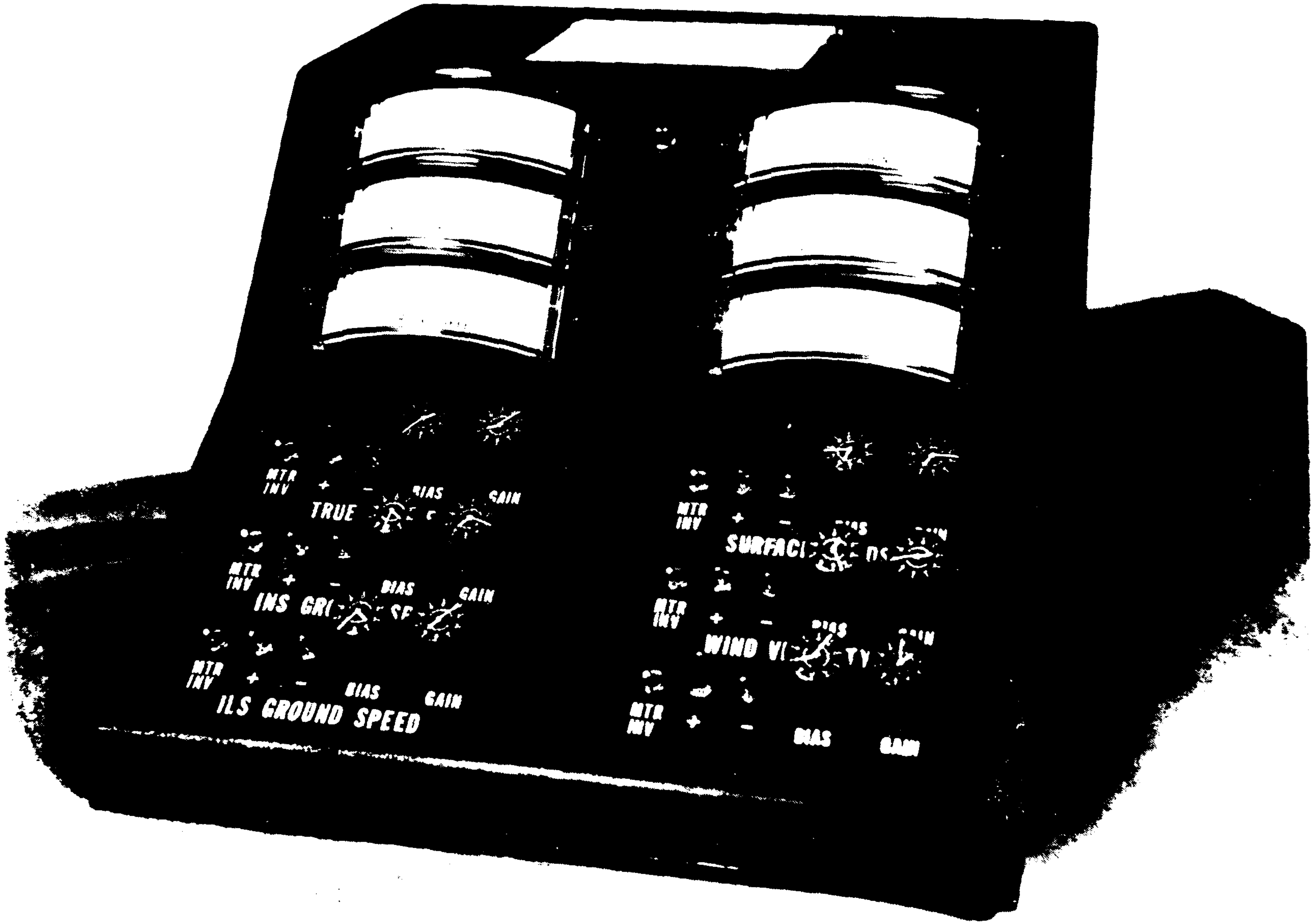


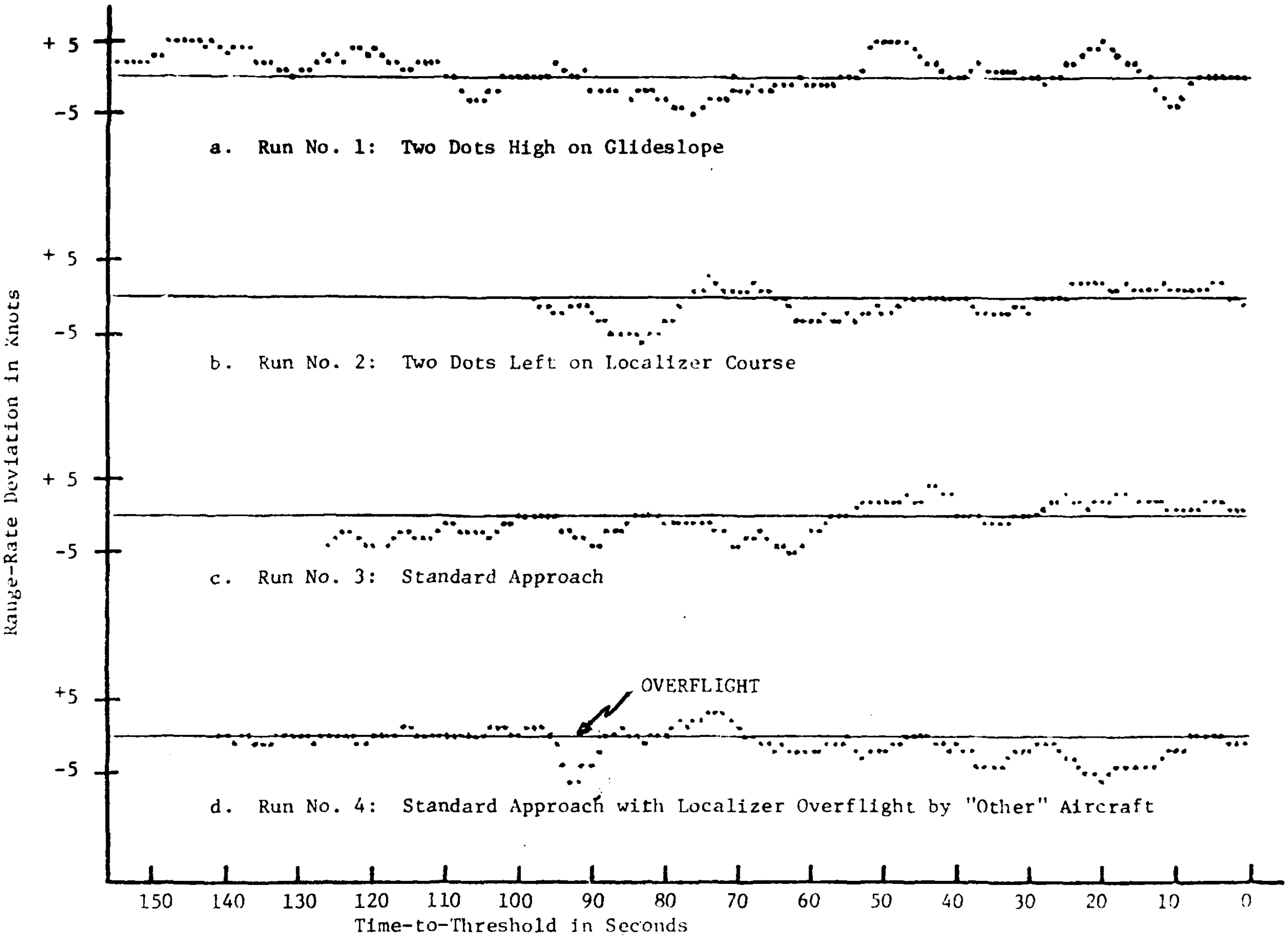
Figure 5-[illegible]. Photograph of Demonstration Flight Test Panel

5.3 TEST RESULTS

The INS groundspeed was used as the standard reference data during all runs and the localizer range rate was compared to that reference data to obtain range rate deviation. The results are illustrated by Figure 5- 5 The range rate deviation on all runs was within about ±5 knots, and normally was considerably less than this amount. The mean value of the deviation was less than 2 knots. The maximum deviation of about 7 knots occurred during a localizer overflight by another aircraft, that shadowed the localizer signal. This error is attributed to the automatic gain control, and can be corrected by a design modification. All range rate deviations are within the limits necessary to provide useful groundspeed information for wind shear measurement avionics.

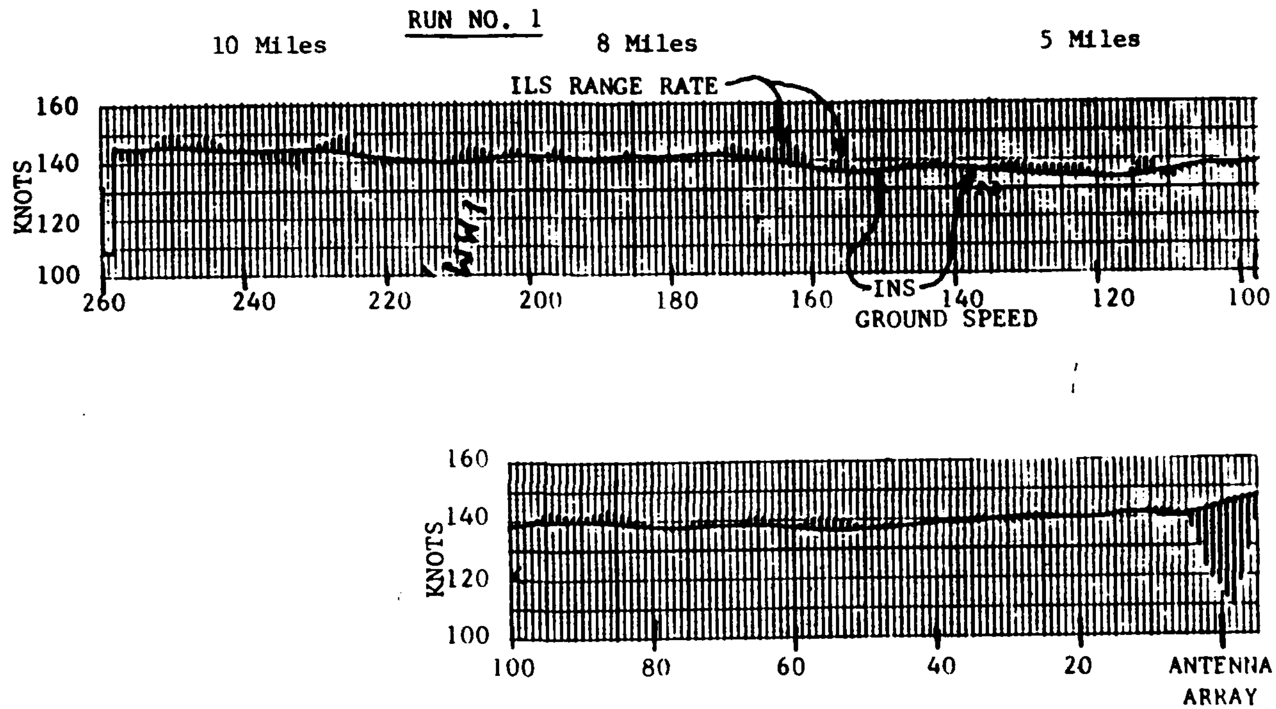
Subsequent flight tests, shown by Figure 5-6a and 5-6b, substantiate the merit of this system. The print-out circuits were modified to show the actual values of INS groundspeed and localizer range rate, and also to clearly show the difference values. The INS groundspeed is shown by the main trace, and the localizer range rate by periodic "ticks" above or below the main trace. The abcissa on these figures again shows time-to-go to the localizer array. The range rate deviations, as in the Figure 5-5 runs, are in the limits demanded by wind shear avionics requirements.

The flight test recordings of the front course approaches, reproduced by Figures 5-7a and 5-7b, show range rate with deviations within ±2 knots during most of these approaches, and never exceeding ±4 knots.



Notes: 1. Range Rate Dots at One Second Intervals
2. All Approaches on Back Course to "Imaginary" Runway

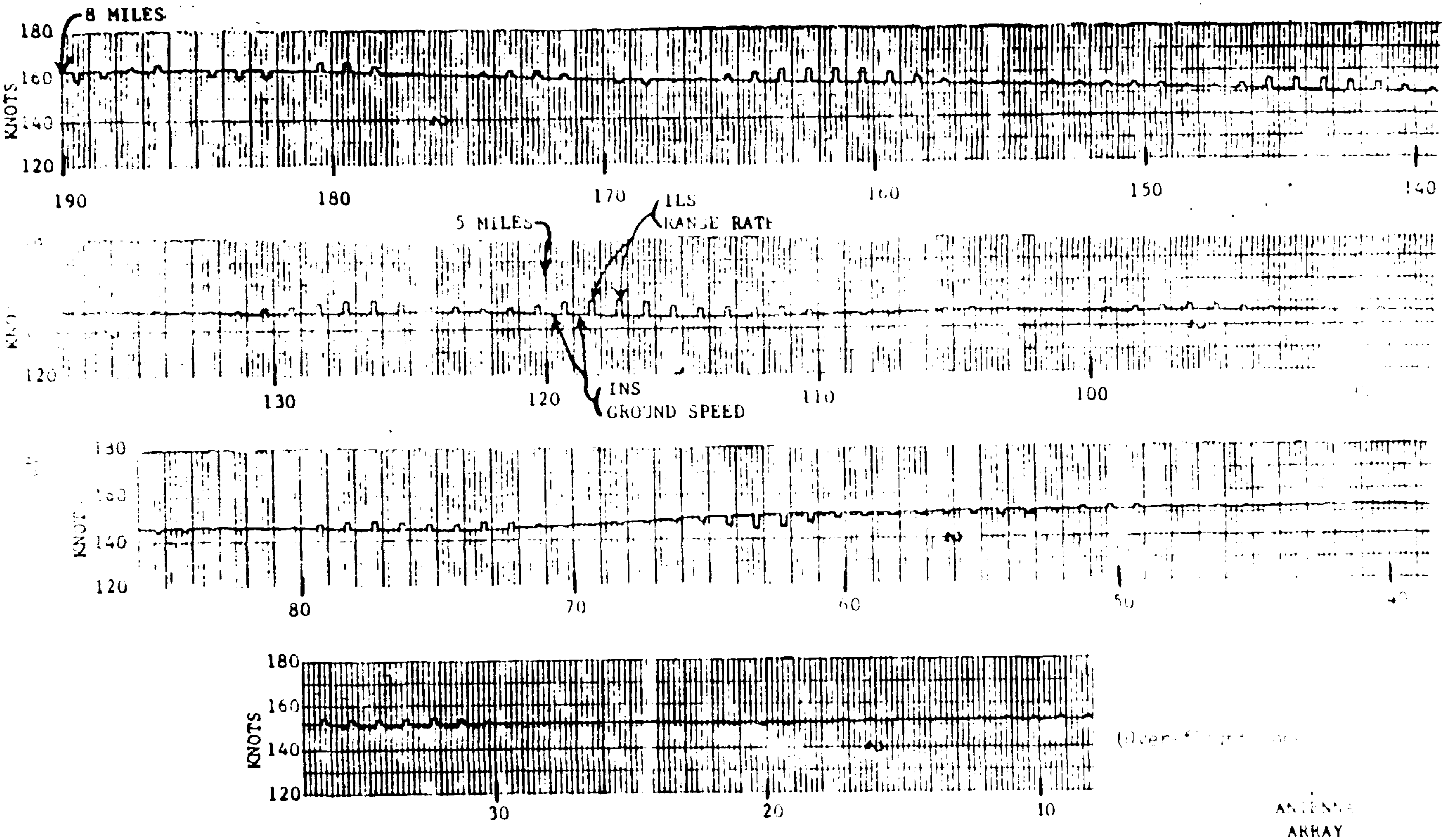
Figure 5-5. Localizer Range-Rate Reference INS Groundspeed



NOTE: These are copies of actual flight test recordings

Figure 5-6a. Localizer Range Rate and INS Ground Speed

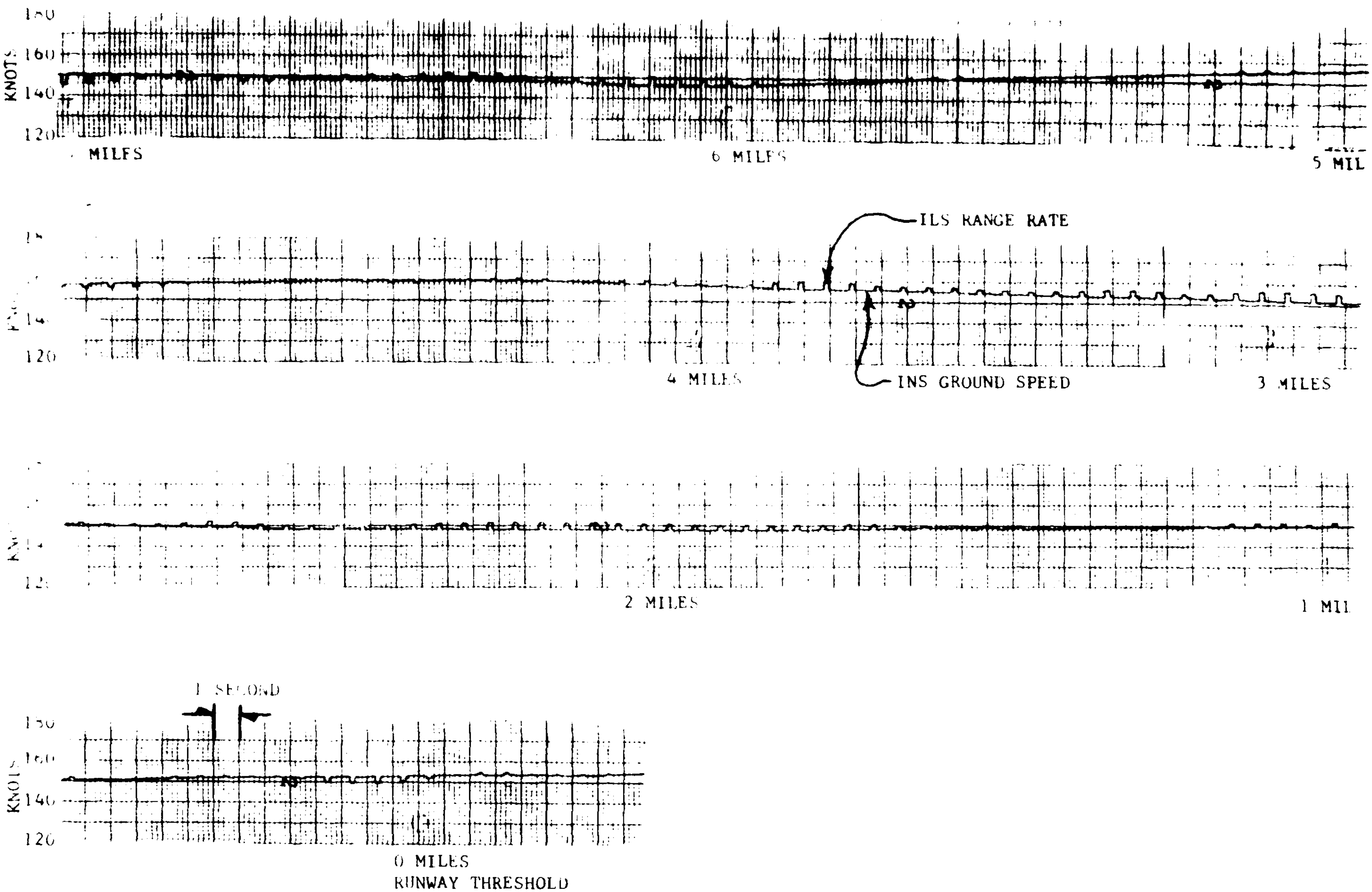
RUN NO. 2 BACK COURSE APPROACH



NOTE: These are copies of actual flight test recordings.

Figure 5-6b. Localizer Range Rate and INS Ground Speed

RUN NO. 1 FRONT COURSE APPROACH

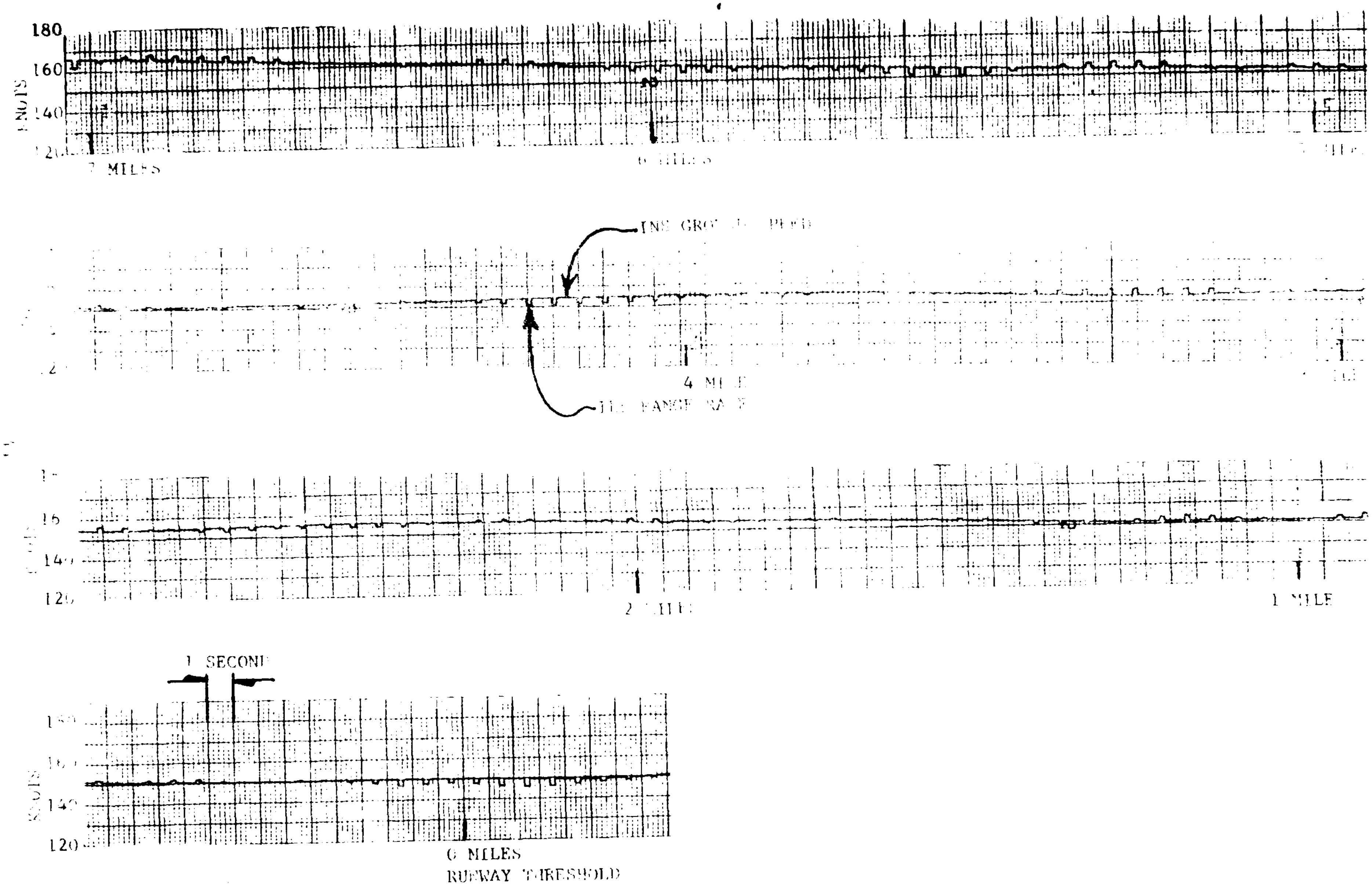


HORZ. = 0.2 SEC./DIV.
VERT. = 2 KTS./DIV.

Figure 5-7a. ILS RANGE RATE AND INS GROUND SPEED

DEC. 12, 1980
USAF TROUT 99
ANDREWS AFB

RUN NO. 2 FRONT COURSE APPROACH



HORZ. = 0.2 SEC./DIV.
VERT. = 2 KTS./DIV.

Figure 5-7b. ILS RANGE RATE AND INS GROUND SPEED

DEC. 12,

6. EQUIPMENT COST

The total cost of all equipment for this range rate measurement system is considerably less than that of other available equivalent systems, such as inertial, Doppler, and radar systems.

6.1 GROUND EQUIPMENT

The ground equipment cost, in production, is estimated at less than $8000. This includes $4000 for the rubidium clock and $4000 for the associated electronics. The equipment will be provided by the Government.

6.2 AIRBORNE EQUIPMENT

The airborne equipment cost, in production quantities, is estimated at $4500. This includes $500 for the quartz clock, and $4000 for the associated electronics. This cost would be increased by about $3500 for airborne equipment using a rubidium clock.

7. CONCLUSIONS

The localizer range rate measurement system described by this report provides groundspeed on final approach, with sufficient accuracy and response time to serve as a valuable input to a wind shear avionics package. The cost of the system is considerably less than any other available system that provides equivalent capabilities. The necessary additional modulation on the localizer signal does not deteriorate the primary course generating function of that equipment. The demodulation and processing equipment required to extract range rate from the Doppler shift of the localizer modulation does not deteriorate the primary course measurement function of the localizer receiver. This integrated package provides a cost effective interim solution to the measurement of groundspeed during final approach.

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